JOURNAL
OF
THE FRANKLIN INSTITUTE
DEVOTED TO SCIENCE AND THE MECHANIC ARTS

VOL. CLXXVIII NOVEMBER, 1914 No. 5

THE THUNDERSTORM AND ITS PHENOMENA.*

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Introduction.—A thunderstorm, as its name implies, is a storm characterized by thunder and lightning, just as a dust storm is one characterized by a great quantity of flying dust. But the dust is never in any sense the cause of the storm that carries it along, nor, so far as known, does either thunder or lightning have any influence on the course—genesis, development, or termination—of even those storms of which they form, in some respects, the most important features. No matter how impressive or how terrifying these phenomena may be, they never are anything more than mere incidents to or products of the peculiar storms they accompany, as will be made clear by what follows. In short, they are never in any sense either storm-originating or storm-controlling factors.

Origin of Thunderstorm Electricity.—A knowledge, or at least a good working hypothesis, of how the great amount of electricity incident to thunderstorms is generated, is absolutely essential to their logical explanation; that is, to a clear understanding of the probable interrelations between their many phenomena.

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Fortunately such an hypothesis, or theory, rather, since it is abundantly supported by observations and by laboratory experiments, is available as a result of work done on this subject in India by Dr. G. C. Simpson,[1] of the Indian Meteorological Department.

Dr. Simpson's observations, just referred to, were obtained at Simla, India, at an elevation of about 7000 feet above sea level, and covered all of the monsoon seasons, that is, roughly, April 15 to September 15, of 1908 and 1909. He also obtained observations of the electrical conditions of the snow at Simla during the winter of 1908–9.

A tipping-bucket rain gauge gave an automatic continuous record of the rate and time of rainfall, while a Bendorf[2] self-registering electrometer marked the sign and potential of the charge acquired during each two-minute interval. A second Bendorf electrometer registered the potential gradient near the earth, and a coherer of the type used in radiotelegraphy registered the occurrence of each lightning discharge.

All obvious sources of error were examined and carefully guarded against. Hence it would seem that the conclusions drawn from the thousands of observations given in the memoir are fully justified; and especially so since several independent series of similar observations made at different times, by different people, and at places widely separated, have given confirmatory results in every case. Simpson's records show that—

(1) The electricity brought down by the rain was sometimes positive and sometimes negative.

(2) The total quantity of positive electricity brought down by the rain was 3.2 times greater than the total quantity of negative electricity.

(3) The period during which positively charged rain fell was 2.5 times longer than the period during which negatively charged rain fell.

(4) Treating charged rain as equivalent to a vertical current of electricity, the current densities were generally smaller than 4×10^{-15} ampères per square centimetre; but on a few occasions greater current densities, both positive and negative, were recorded.

(5) Negative currents occurred less frequently than positive currents, and the greater the current density the greater the preponderance of the positive currents.

(6) The charge carried by the rain was generally less than 6 electrostatic units per cubic centimetre of water, but larger charges were occasionally recorded, and in one exceptional storm (May 13, 1908) the negative charge exceeded 19 electrostatic units per cubic centimetre.

(7) As stated in paragraph (3), positive electricity was recorded more frequently than negative, but the excess was the less marked the higher the charge on the rain.

(8) With all rates of rainfall positively charged rain occurred more frequently than negatively charged rain, and the relative frequency of positively charged rain increased rapidly with increased rate of rainfall. With rainfall of less than about 1 millimetre in two minutes, positively charged rain occurred twice as often as negatively charged rain, while with greater intensities it occurred fourteen times as often.

(9) When the rain was falling at a less rate than about 0.6 millimetre in two minutes, the charge per cubic centimetre of water decreased as the intensity of the rain increased.

(10) With rainfall of greater intensity than about 0.6 millimetre in two minutes the positive charge carried per cubic centimetre of water was independent of the rate of rainfall, while the negative charge carried decreased as the rate of rainfall increased.

(11) During periods of rainfall the potential gradient was more often negative than positive, but there were no clear indications of a relationship between the sign of the charge on the rain and the sign of the potential gradient.

(12) The data do not suggest that the negative electricity occurs more frequently during any particular period of a storm than during any other.

Concerning his observation on the electrification of snow Dr. Simpson says:

So far as can be judged from the few measurements made during the winter of 1908–9 it would appear that:

(1) More positive than negative electricity is brought down by snow in the proportion of about 3.6 to 1.

(2) Positively charged snow falls more often than negatively charged.

(3) The vertical electric currents during snowstorms are on the average larger than during rainfall.

(4) The charge per unit mass of precipitation is larger during snowfall than during rainfall.

While these observations were being secured a number of well-devised experiments were made to determine the electrical effects of each obvious process that takes place in the thunderstorm.

Freezing and thawing, air friction, and other things were tried, but none produced any electrification. Finally, on allowing drops of *distilled* water to fall through a vertical blast of air of sufficient strength to produce some spray, positive and important results were found, showing:

(1) That breaking of drops of water is accompanied by the production of both positive and negative ions.

(2) That three times as many negative ions as positive ions are released.

Now, a strong upward current of air is one of the most conspicuous features of the thunderstorm. It is always evident in the turbulent cauliflower heads of the cumulus cloud, the parent, presumably, of all thunderstorms. Besides, its inference is compelled by the occurrence of hail, a frequent thunderstorm phenomenon, whose formation requires the carrying of raindrops and the growing hailstones repeatedly to cold and therefore high altitudes. And from the existence of hail it is further inferred that an updraft of at least 8 metres per second must often occur within the body of the storm, since, as experiment shows, it requires approximately this velocity to support the larger drops, and even a greater velocity to support the average hailstone.

Experiment also shows that rain cannot fall through air of ordinary density whose upward velocity is greater than about 8 metres per second, or itself fall with greater velocity through still air; that in such a current, or with such a velocity, drops large enough, if kept intact, to force their way down, or, through the action of gravity, to attain a greater velocity than 8 metres per second with reference to the air, whether still or in motion, are so blown to pieces that the increased ratio of supporting area to total mass causes the resulting spray to be carried aloft or left behind, together with, of course, all original smaller drops. Clearly, then, the updrafts within a cumulus cloud frequently must break up at about the same level innumerable drops which, through coalescence, have grown beyond the critical size, and

thereby, according to Simpson's experiments, produce electrical separation within the cloud itself. Obviously, under the turmoil of a thunderstorm, its choppy surges and pulses, such drops may be forced through the cycle of union (facilitated by any charges they may carry) and division, of coalescence and disruption, from one to many times, with the formation on each at every disruption, again *according to experiment*, of a correspondingly increased electrical charge. The turmoil compels mechanical contact between the drops, whereupon the charges break down the surface tension and insure coalescence. Hence, once started, the electricity of a thunderstorm rapidly grows to a considerable maximum.

After a time the larger drops reach, here and there, places below which the updraft is small—the air cannot be rushing up everywhere—and then fall as positively charged rain, because of the processes just explained. The negative electrons in the meantime are carried up into the higher portions of the cumulus, where they unite with the cloud particles and thereby facilitate their coalescence into negatively charged drops. Hence, the heavy rain of a thunderstorm should be positively charged, as it almost always is, and the gentler portions negatively charged, which also usually is the case.

Such in brief is Dr. Simpson's theory of the origin of the electricity in thunderstorms, a theory that fully accounts for the facts of observation and in turn is itself abundantly supported by laboratory tests and simulative experiments.

If this theory is correct, and it seems well founded, it must follow that the one essential to the formation of the giant cumulus cloud, namely, the rapid uprush of moist air, is also the one essential to the generation of the electricity of thunderstorms. Hence, the reason why lightning seldom if ever occurs except in connection with a cumulus cloud is understandable and obvious. It is simply because the only process that can produce the one is also the process that is necessary and sufficient for the production of the other.

The Violent Motions of Cumulus Clouds.—From observations, and from the graphic descriptions of the few balloonists who have experienced the trying ordeal of passing through the heart of a thunderstorm, it is known that there is violent vertical motion and much turbulence in the middle of a large cumulus

cloud, a fact which, so far as it relates to the theory alone of the thunderstorm, it would be sufficient to accept without inquiring into its cause. However, to render the discussion more nearly complete, it perhaps is worth while, since it is a mooted question, to inquire what the probable cause of the violent motions in large cumulus clouds really is—motions which, in the magnitude of their vertical components and degree of turmoil, are never exhibited by clouds of any other kind nor met with elsewhere by either manned, sounding, or pilot balloons.

It has been shown by von Bezold [3] that sudden condensation from a state of supersaturation, and also sudden congelation of undercooled cloud droplets, would, as a result of the heat thus liberated, cause an equally sudden expansion of the atmosphere, and thereby turbulent motions analogous to those observed in large cumuli. However, as von Bezold himself points out, it is not evident how either the condensation or the freezing could suddenly take place throughout a cloud volume great enough to produce the observed effects. Besides, these eruptive turmoils, whatever their genesis, undoubtedly originate and run their course in regions already filled with cloud particles in the presence of which no appreciable degree of supersaturation can occur. Hence the rapid uprush and the violent turbulence in question obviously must have some other cause; and this we shall find in the difference between the actual temperature gradient of the surrounding atmosphere and the adiabatic temperature gradient of the saturated air within the cloud itself.

Consider a warm summer afternoon, temperature 30° C., say, and assume the dew point to be 15° C. Now, the adiabatic decrease of temperature of non-saturated air is about 1° C. per 100 metres change in elevation, and therefore, under the assumed conditions, vertical convection of the surface air causes condensation to begin at an elevation of approximately 1.5 kilometres. From this level, however, so long as the cloud particles are carried up with the rising air, the rate of temperature decrease, for at least a couple of kilometres, is much less—at first about one-half the previous rate. After a considerable rise above the level of initial condensation, half a kilometre, say, the raindrops have so increased in size as to lag behind the upward current and even to drop out, while, at the same time, the amount of moisture condensed per degree fall of temperature grows rapidly less. Hence,

for both reasons—because the heat of the condensed water is no longer available to the air from which it was condensed, the drops having been left behind, and because but little latent heat is to be had from further condensation, there being but little water vapor left—the rate of temperature decrease again approaches the adiabatic gradient of dry air, or 1° C. per 100 metres change of elevation.

Obviously, then, for some distance above the level at which condensation begins to set free its latent heat, the temperature of the rising mass of moist air departs farther and farther from the temperature of the surrounding atmosphere at the same level, and therefore its buoyancy for a time as steadily increases. But, of course, as explained above, this increase of buoyancy does not continue to any great altitude.

In the lower atmosphere continuous and progressive convection builds up the adiabatic gradient so gradually that no great difference between the temperature of the rising column and that of the adjacent atmosphere is anywhere possible. Hence, under ordinary conditions, the uprush in this region is never violent. But whenever the vertical movement of the air brings about a considerable condensation it follows, as above explained, that there is likely to be an increase in its buoyancy, and hence a more or less rapid upward movement of the central portion, like air up a heated chimney, and for the same reason, together with, because of viscosity, a rolling and turbulent motion of the sides, of the type so often seen in towering cumulus clouds. Obviously, too, the uprushing columns of air must ascend somewhat beyond its point of equilibrium, and then, because slightly undercooled, correspondingly drop back.

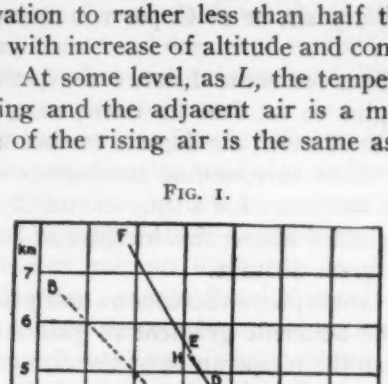
Fig. 1, based upon approximately average conditions, illustrates the points just explained. The elevation is in kilometres and the temperature in degrees centigrade.

AB is the approximate temperature gradient for non-saturated air, about 1° C. per 100 metres change in elevation. *GCKDEF* is the supposed temperature gradient before convection begins, or a decrease, in accordance with observations, of 6° C., approximately, per kilometre increase of elevation, except near the surface, where the temperature decrease, before convection has begun, ordinarily is less rapid.

As convection sets in, the temperature decrease near the

surface soon approximates the adiabatic gradient for dry air, and this condition extends gradually to greater altitudes, till, in the assumed case, condensation begins at the level *C*, or where the temperature is 15° C. Here the temperature decrease, under the assumed conditions, suddenly changes from 10° C. per kilometre increase of elevation to rather less than half that amount, but slowly increases with increase of altitude and consequent decrease of temperature. At some level, as *L*, the temperature difference between the rising and the adjacent air is a maximum. At *D* the temperature of the rising air is the same as that of the air

FIG. 1.



Temperature gradients within (*CLD*) and without (*CKD*) cumulus clouds.

adjacent, but its momentum presumably carries it on to some such level as *H*. Within the rising column, then, the temperature gradient is approximately given by the curve *ACLDHE*, while the temperature gradient of the surrounding air is given by the curve *ACKDEF*.

The cause, therefore, of the violent uprush and turbulent condition within large cumulus clouds is, presumably, the difference between the temperature of the inner or warmer portions of the cloud itself and that of the surrounding atmosphere at the same level, as indicated by their respective temperature gradients *CLD* and *CKD*. Clearly, too, while some air must flow into the condensation column all along its length, the greatest pressure

difference, and, therefore, the greatest inflow, obviously is at its base. After the rain has set in, however, this basal inflow is from immediately in front of the storm, and necessarily so, as will be explained later.

Convectional Instability.—Rapid vertical convection of humid air, as we have seen, is essential to the production of the cumulus cloud and, therefore, to the generation of the thunderstorm. Hence it is essential to consider the conditions under which the vertical temperature gradient necessary to this convection can be established. These are:

1. Strong surface heating, especially in regions of light winds; a frequent occurrence.

The condition that the winds be light is not essential or, perhaps, even favorable to the genesis of all thunderstorms—only the local or heat variety, and favorable to these simply because heavy winds tend to prevent the formation of isolated rising columns of air, the progenitor of this particular type of storm.

2. The overrunning of one layer of air by another at a temperature sufficiently lower to induce convection, well-nigh the sole cause of ocean thunderstorms and also of frequent occurrence on land.

3. The underrunning and consequent uplift of a saturated layer of air by a denser layer; a frequent occurrence to a greater or less extent, and presumably, therefore, at least an occasional one of sufficient magnitude to produce a thunderstorm.

Here the underrunning air lifts both the saturated layer and the superincumbent unsaturated layer, and thereby forces each to cool adiabatically. But as both layers are lifted equally while, because of the latent heat of condensation, the saturated layer cools much slower than the dry, it follows that a sufficient mechanical lift of a saturated layer of air would establish between it and the non-saturated layer above a superadiabatic temperature gradient and thereby produce local convection, cumulus clouds, and, perhaps, a thunderstorm.

Periodic Recurrence of Thunderstorms.—While thunderstorms may occur at any hour of any day they nevertheless have three distinct periods of maximum occurrence: *a*, daily, *b*, yearly, and *c*, irregularly cyclic. Each maximum depends upon the simple facts that the more humid the air and the more rapid the local vertical convections the more frequent and also the more intense

the thunderstorms, for the obvious reason that it is rapid vertical convection of humid air that produces them.

Daily Land Period.—Vertical convection of the atmosphere over land areas is most pronounced when the surface is most heated; that is, during afternoons. Hence the hours of maximum frequency of inland or continental thunderstorms are, in most places, 2 to 4 P.M.

Daily Ocean Period.—Because of evaporation and of the high specific heat of water the surface temperature of the ocean increases but little during the day, and because of convection it decreases but slightly at night. Indeed, the diurnal temperature range of the ocean surface usually is but a small fraction of 1° C., while that of the atmosphere at from 500 to 1000 metres elevation is several fold as great.[4] Hence those temperature gradients over the ocean that are favorable to rapid vertical convection are most frequent during the early morning hours, and, therefore, the maximum of ocean thunderstorms usually occurs between midnight and 4 A.M.

Yearly Land Period.—Just as inland thunderstorms are most frequent during the hottest hours of the day, so too, and for the same reason, they are, in general, most frequent over the land during the hottest months of the year, or, rather, during those months when the amount of surface heating and, therefore, the vertical temperature gradient is a maximum.

Hence, in middle latitudes, where there are no late spring snows to hold back the temperatures, the month of maximum frequency often is June. In higher latitudes, where the strong surface heating is more or less delayed, the maximum occurs in July or even August.

Yearly Ocean Period.—Over the oceans, on the other hand, temperature gradients favorable to the genesis of thunderstorms, and, therefore, the storms themselves, occur most frequently during the winter and least frequently during the summer. This is because the temperature of the air at some distance above the surface, being largely what it was when it left the windward continent, greatly changes from season to season, while that of the water, and, of course, the air in contact with it, changes but little through the year. That is, over the oceans the average decrease of temperature with increase of elevation obviously is least and,

therefore, thunderstorms fewest in summer, and greatest, with storms most numerous, in winter.

Cyclic Land Period.—Since thunderstorms are accompanied by rain and since over land they are most numerous during summer, it would appear that they must occur most frequently either in warm or in wet years and least frequently in cold or in dry years. Further, if it should happen, as it actually does, that, for the earth as a whole, warm years are also wet years and dry years cold years, it would appear logically certain that, for the entire world, the maximum number of thunderstorms must belong to the years that are wet and warm and the minimum to those that are cold and dry.

A complete statistical examination of these statements is not possible, owing to the fact that meteorological data are available for only portions of the earth's surface and not for the whole of it. Nevertheless, well-nigh conclusive data do exist. The annual rainfall, for instance, to the leeward of a large body of water obviously must bear the same relation to the annual average windward temperature that the total annual precipitation over the entire world does to the annual average world temperature. In each case the amount of evaporation or amount of water vapor taken into the atmosphere, and, therefore, the amount of subsequent precipitation, clearly must increase and decrease with the temperature. An excellent test and complete support of this deduction is furnished by Fig. 2, in which the full line represents the smoothed annual European precipitation,[5] and the dotted line smoothed annual average American temperatures.

Beyond a reasonable doubt, therefore, for the world as a whole, warm years are wet and cold ones are dry. Hence, as above stated, it is practically certain that the maxima of thunderstorms occur during years that are wet, or warm, if we prefer, for the two are synchronous, and the minima during years that are dry, or cold. A partial and, so far as it goes, a confirmatory statistical test of this conclusion is given by Fig. 3. The lower group of curves is based on an exhaustive study by Dr. von Gulik [6] of thunderstorms and lightning injuries in Holland. The continuous zigzag line gives the actual annual number of thunderstorm days and the continuous curved line the same numbers smoothed. The broken lines give, respectively, the actual and the smoothed values of the annual average precipitation. The upper

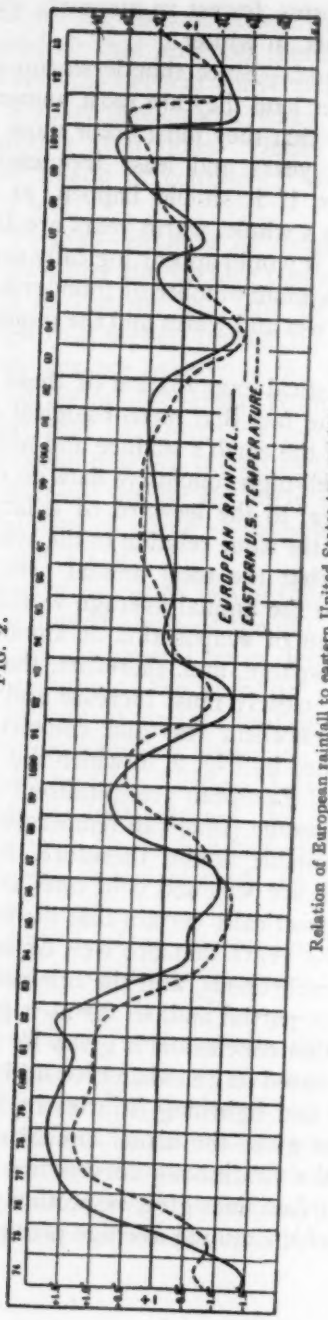
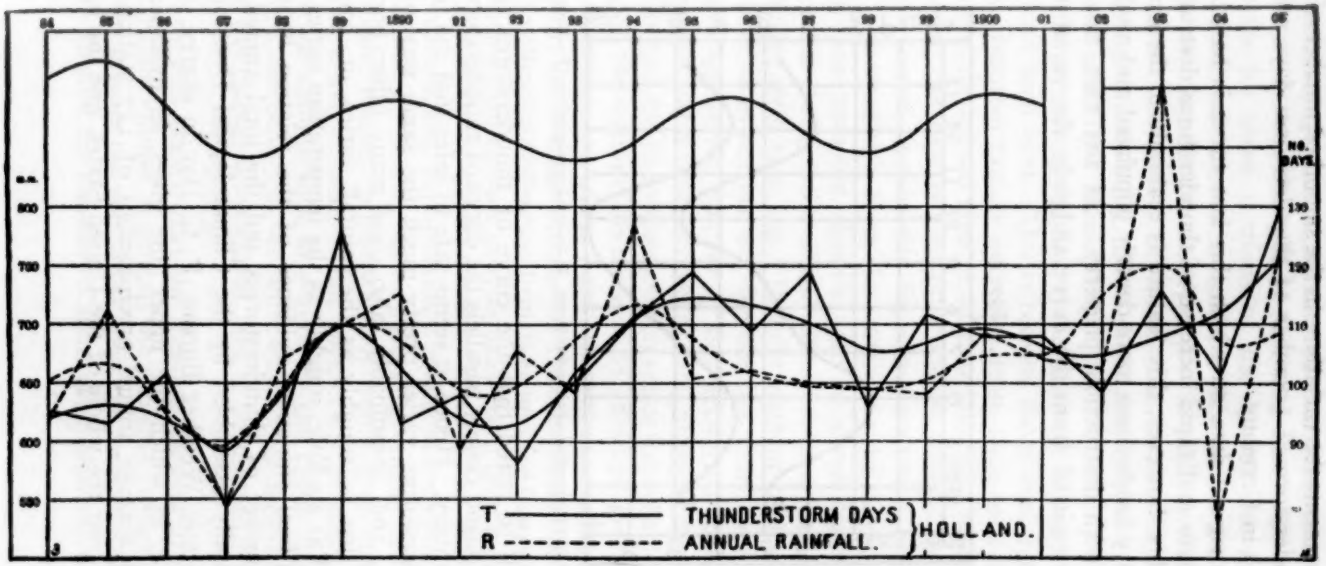


FIG. 2.

Relation of European rainfall to eastern United States temperature.

FIG. 3.

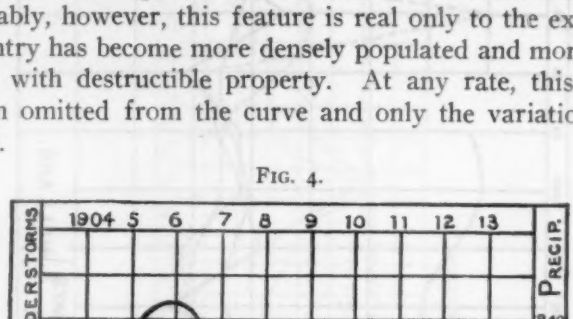


Relation of annual number of thunderstorm days to total annual precipitation—Holland.

curve represents the variations in the smoothed number of destructive thunderstorms [7] (number of thunderstorm days not readily available) in Germany.

The original data on which this last curve is based indicate a continuous and rapid increase of thunderstorm destructiveness. Presumably, however, this feature is real only to the extent that the country has become more densely populated and more thickly studded with destructible property. At any rate, this element has been omitted from the curve and only the variation factor retained.

FIG. 4.



Relation of annual number of thunderstorms, *T*, to total precipitation, *P*—United States.

It will be noted that the curve of thunderstorm frequency for all Holland closely parallels the curve of thunderstorm injury in all Germany. Hence, it seems safe to infer that the frequency of thunderstorms varies pretty much the same way over both countries, and, presumably, also over many other portions of Europe; that is, roughly as the rainfall varies, or, considering the world as a whole, roughly as the temperature varies.

Additional statistical evidence of the relation between the annual number of thunderstorms and the total annual precipitation, kindly assembled by the Climatological Division of the United States Weather Bureau, P. C. Day in charge, is shown by Fig. 4, in which the upper line gives, in millimetres, the smoothed average annual precipitations of 127 stations widely scattered over the whole of the United States, and the lower line

the smoothed average annual number of thunderstorms at these same stations. It was thought at first that this relation might differ greatly for those portions of the United States whose climates are radically dissimilar, and for this reason the stations east of the one hundredth meridian provisionally were classed separately from those west of it; but the results for the two sections, being substantially alike, show that for this purpose their division is entirely unnecessary.

As will be seen from the figure, the statistics of only the past ten years have been used. This is because the annual number of such storms reported rapidly decreases from 1904 back to about 1890. Indeed, the annual number of thunderstorms reported per station during the past ten years is almost double the annual number per station (practically the same stations) from 1880 to 1890. The transition from the smaller to the larger number was due in great measure, doubtless, to an alteration in station regulations that changed the official definition of a thunderstorm from "thunder *with* rain" to "thunder *with* or *without* rain." This, however, does not account for the fact that from 1890 to 1904 the average annual number of thunderstorms reported per station increased, at a nearly constant rate, almost 100 per cent. Either the storms did so increase, which seems improbable, or else there was, on the average, an increase of attention given to this particular phenomenon. At any rate, so continuous and so great an increase in the average number of thunderstorms can hardly be accepted without abundant confirmation, and for this reason the earlier thunderstorm records provisionally have been rejected.

Obviously a much closer relation between the number of thunderstorms and total precipitation would hold for some months and seasons than for others, but no such subgrouping of the data has been made, though, presumably, it would give interesting results. The whole purpose of this portion of the study was to arrive at some definite idea in regard to the cyclic change of thunderstorm frequency, to see with what other meteorological phenomena this change is associated, and, if possible, to determine its cause.

Now it is well known that the average temperature of the world as a whole follows in general the sun-spot changes, in the sense that the greater the number of spots the lower the temperature and the smaller the number of spots the higher the tempera-

ture. This regular relation, however, often is greatly modified[8] by the presence in the high atmosphere of volcanic dust, one invariable effect of which is a lower average temperature. Hence, the warm and the cold periods are irregularly cyclic, and also irregular in intensity. Hence, also, the annual amount of precipitation, the frequency of thunderstorms, and many other phenomena must perforce undergo exactly the same irregular cyclic variation.

As already stated, the statistical evidence bearing on these conclusions neither is nor can be complete, but the deductions are so obvious and the statistical data already examined so confirmatory that but little doubt can exist of their general accuracy.

Cyclic Ocean Period.—The record of thunderstorms over the oceans is not sufficiently full to justify any conclusions in regard to their cyclic changes. Possibly, as in the yearly and the daily periods, the ocean cyclic period may be just the reverse of that of the land, but this is not certain.

Geographic Distribution.—The geographic distribution of the thunderstorm may safely be inferred from the fact that it is caused by the strong vertical convection of humid air. From the nature of its formation one would assume, and the assumption is supported by observation, that the thunderstorm must be rare beyond either polar circle, especially over Greenland and over the Antarctic continent, rare over great desert regions wherever situated, and on the other hand, increasingly abundant with increase of temperature and humidity, and, therefore, in general, most abundant in the more rainy portions of the equatorial regions. The east coast of South America from Pernambuco to Bahia is said to be an exception.

Pressure and Temperature Distribution.—In illustrating the occurrence of thunderstorms with reference to the disposition of isobars and isotherms, or the distribution of atmospheric pressure and temperature, typical weather maps of the United States,* Figs. 5–19, have been used, not because the thunderstorms of this country are different in any essential particular from those of other countries, but chiefly as a matter of convenience in making the drawings. To facilitate their study each of the several types

*The author wishes to acknowledge the courteous coöperation of the Forecast Division, U. S. Weather Bureau, in selecting maps typical of thunderstorm conditions in the United States.

discussed is illustrated with three consecutive maps. The first shows the 12-hour antecedent conditions, the second the particular pressure-temperature distribution in question, and the third the 12-hour subsequent conditions.

In these figures the isobars, in corrected inches of mercury, and the isotherms, in Fahrenheit degrees, are marked by full and by dotted lines, respectively. The legend " LOW " is written over a region from which, for some distance in every horizontal direction, the pressure increases. Similarly, the legend " HIGH " applies to a region from which, in every direction, the pressure decreases. The arrows, as is customary on such maps, fly with the wind, while the state of weather is indicated by the usual U. S. Weather Bureau symbols.

Obviously, the key to the geographic distribution of thunderstorms, vertical convection of humid air, is also the key to their location with reference to the existing distribution of barometric pressure. From this standpoint the places of their most frequent occurrence are:

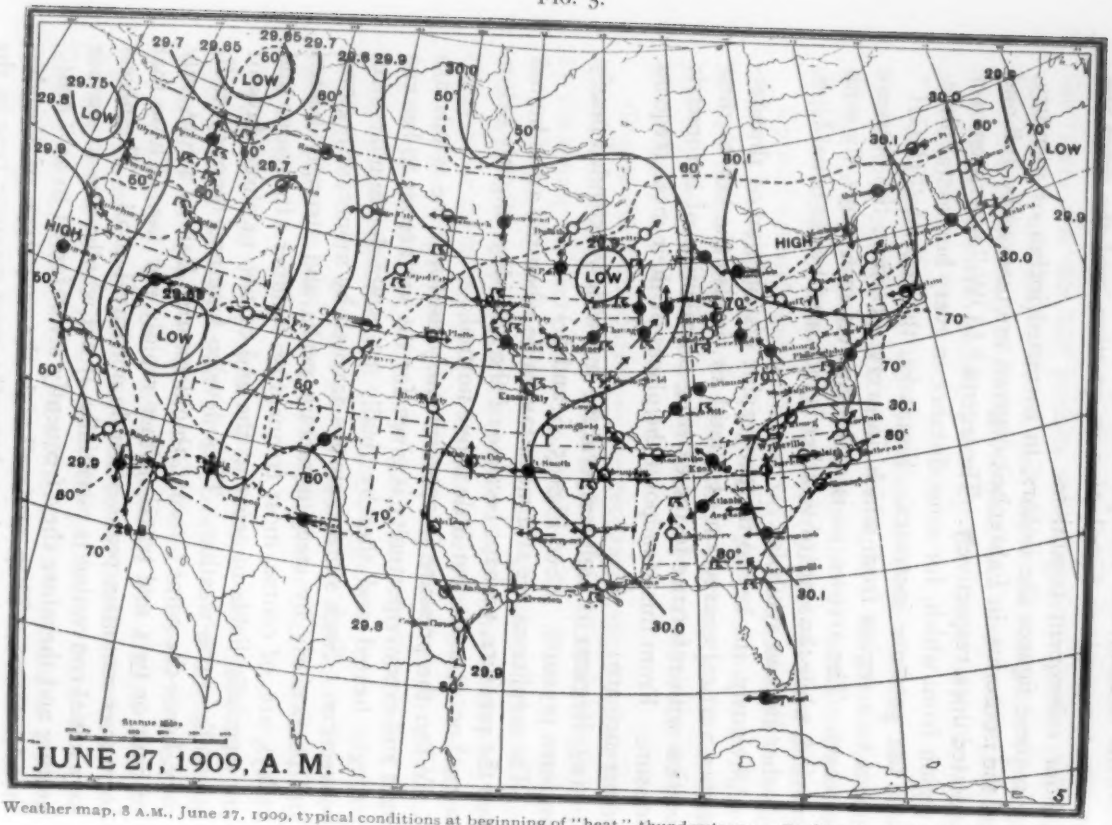
(*a*) Regions of high temperature and widely extended nearly uniform pressure. (See Figs. 5, 6, and 7.)

The conditions are still more favorable when the air is humid and the pressure, perhaps because of the humidity, slightly below normal or, at most, but little above normal.

When the pressure is approximately uniform the winds are light and every opportunity is given for the surface air to become strongly heated and thereby finally to establish thunderstorm convections. Such storms, always favored by mountain regions, and particularly by steep mountain peaks and strongly heated valleys, are, of course, most frequent on summer afternoons and are especially liable to occur at the end of two or three days of unusually warm weather. They develop here and there sporadically, hence the name *" local "* thunderstorm; last, as a rule, only an hour or two, and travel neither rapidly nor far. Those that form over mountain peaks often do not travel at all. The necessary initial convection is essentially, if not wholly, due to surface heating and therefore they frequently are referred to as *" heat "* thunderstorms. They are well-nigh the only type of thunderstorm in the tropics, and, perhaps, the most common type in the warmer portions of the temperate zones.

(*b*) The southeast quadrant (Southern Hemisphere, north-

FIG. 5.

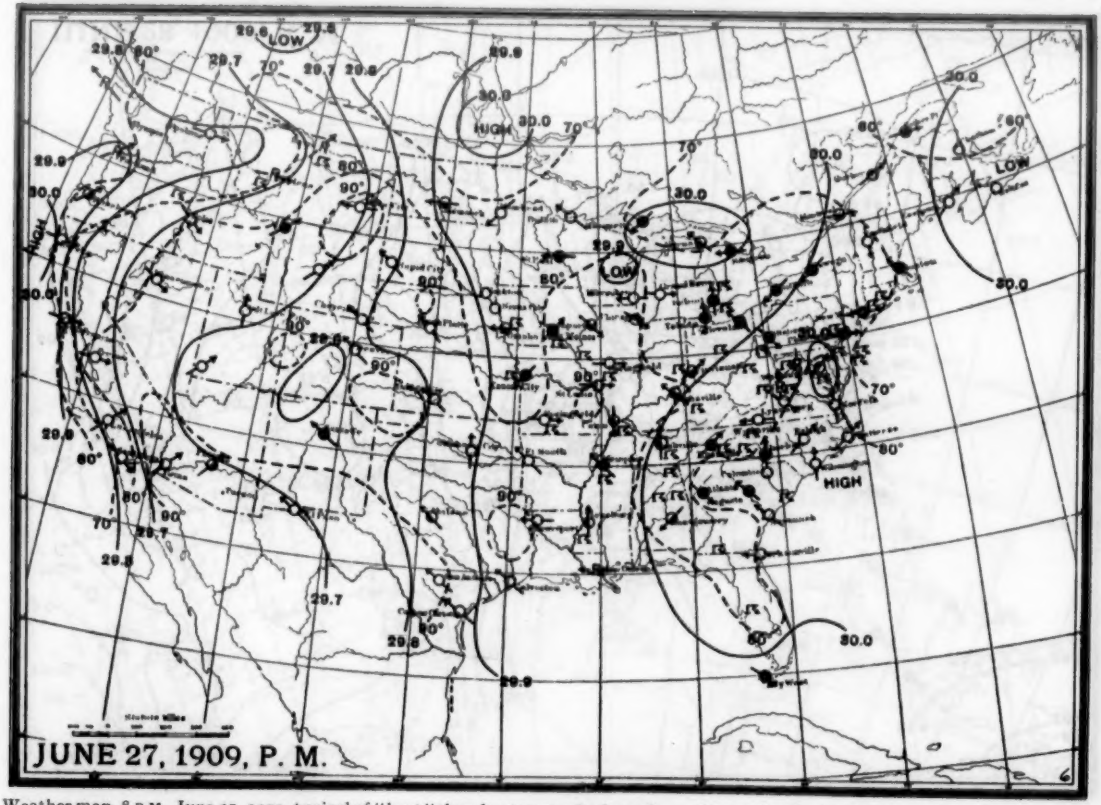


Weather map, 8 A.M., June 27, 1909, typical conditions at beginning of "heat" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 6.

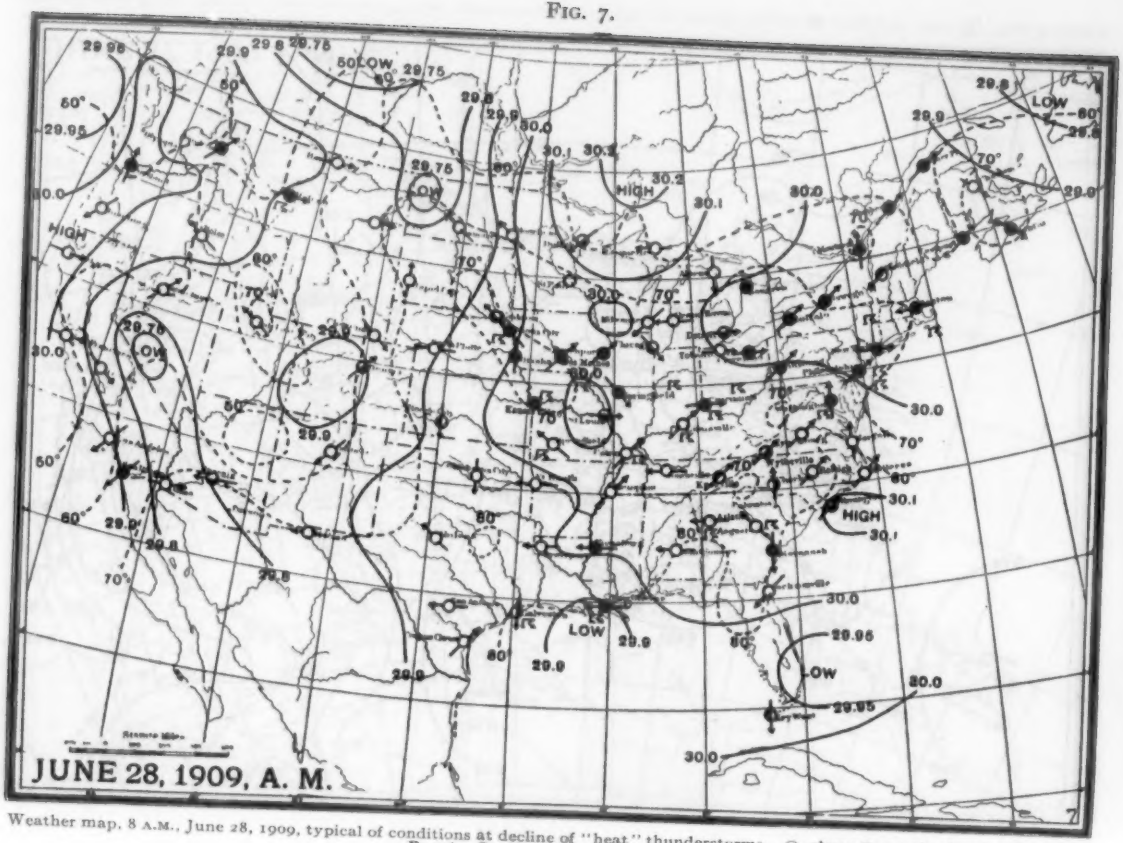
R, rain; R_s, thunderstorm.

FIG. 6.



Weather map, 8 P.M., June 27, 1909, typical of "heat" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 7.

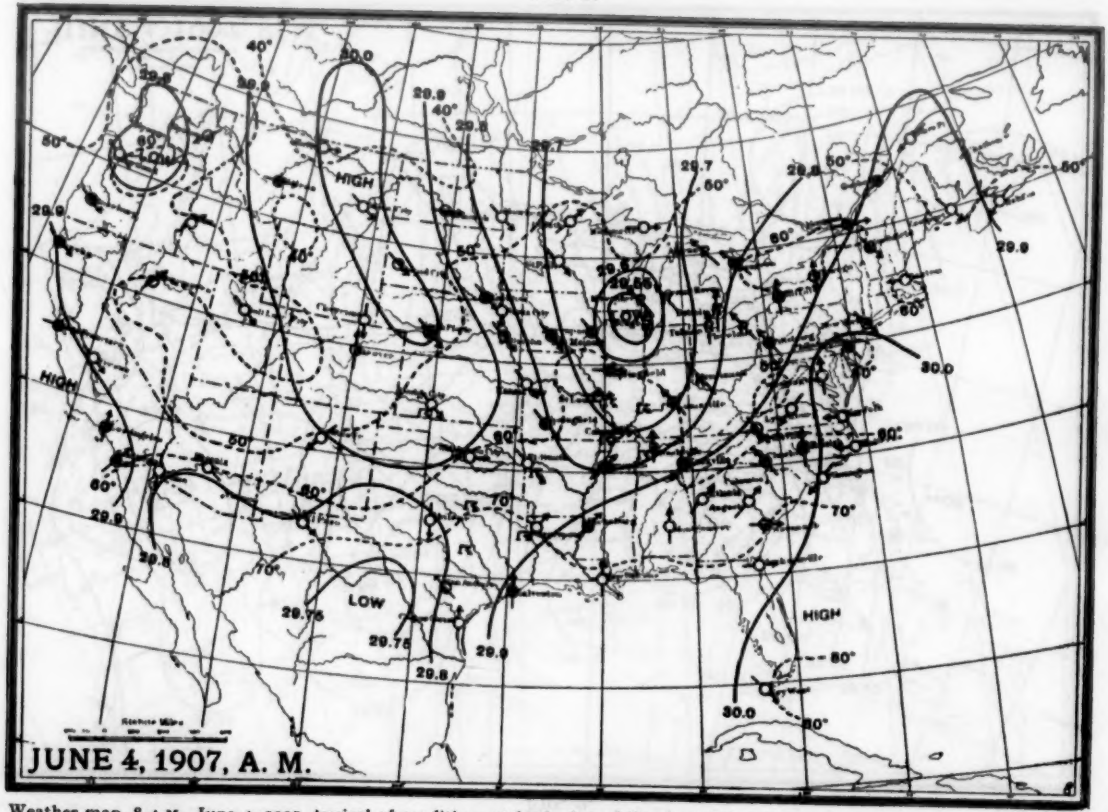


Weather map, 8 A.M., June 28, 1909, typical of conditions at decline of "heat" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_t, thunderstorm.

FIG. 8.

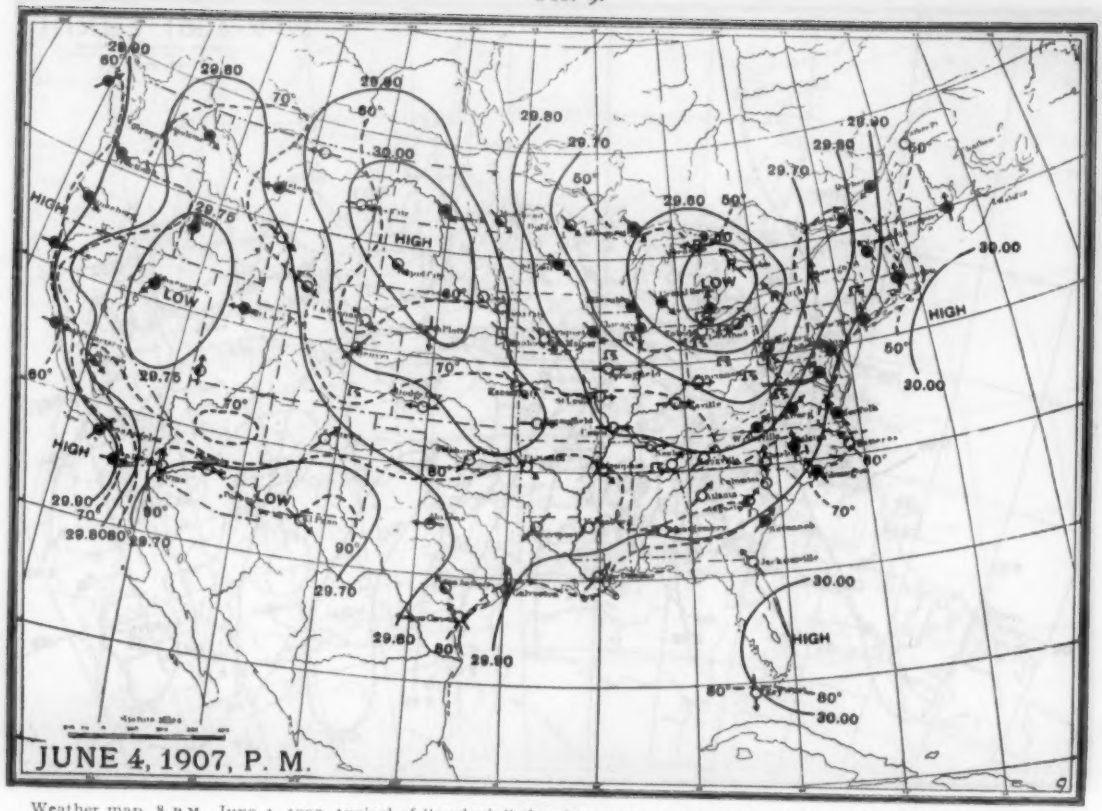
R, rain; R_s, thunderstorm.

FIG. 8.



Weather map, 8 A.M., June 4, 1907, typical of conditions at beginning of "cyclonic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 9.

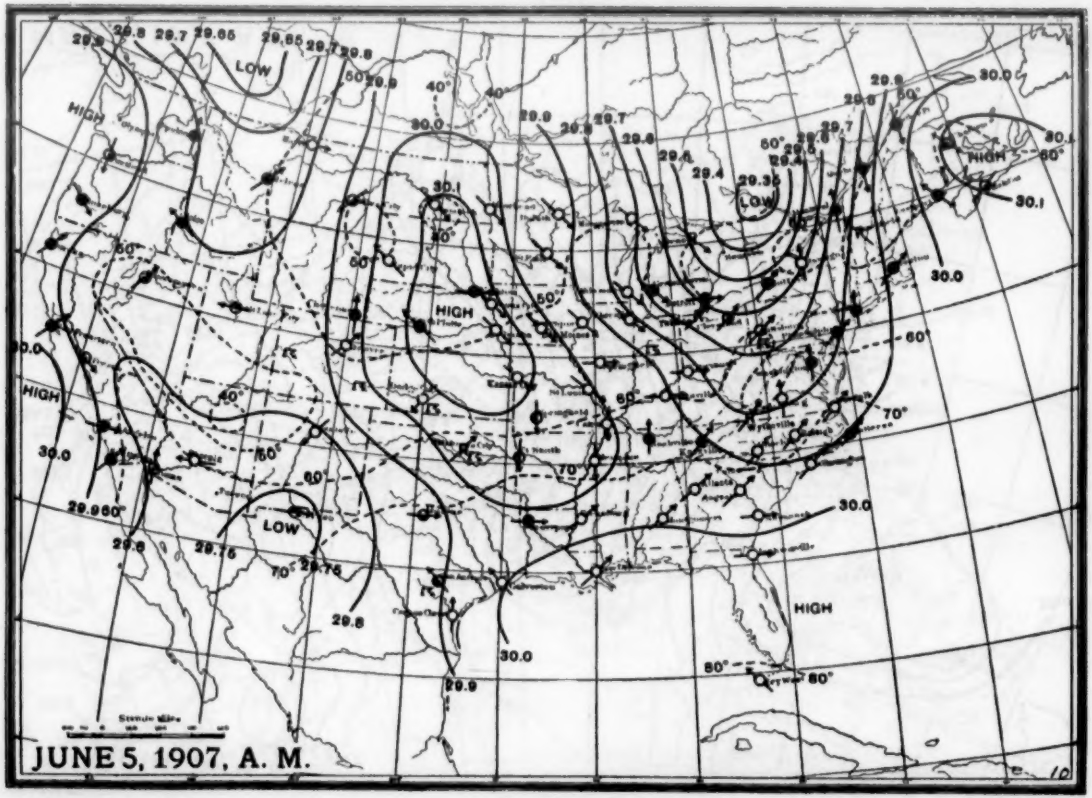


Weather map, 8 P.M., June 4, 1907, typical of "cyclonic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 10.

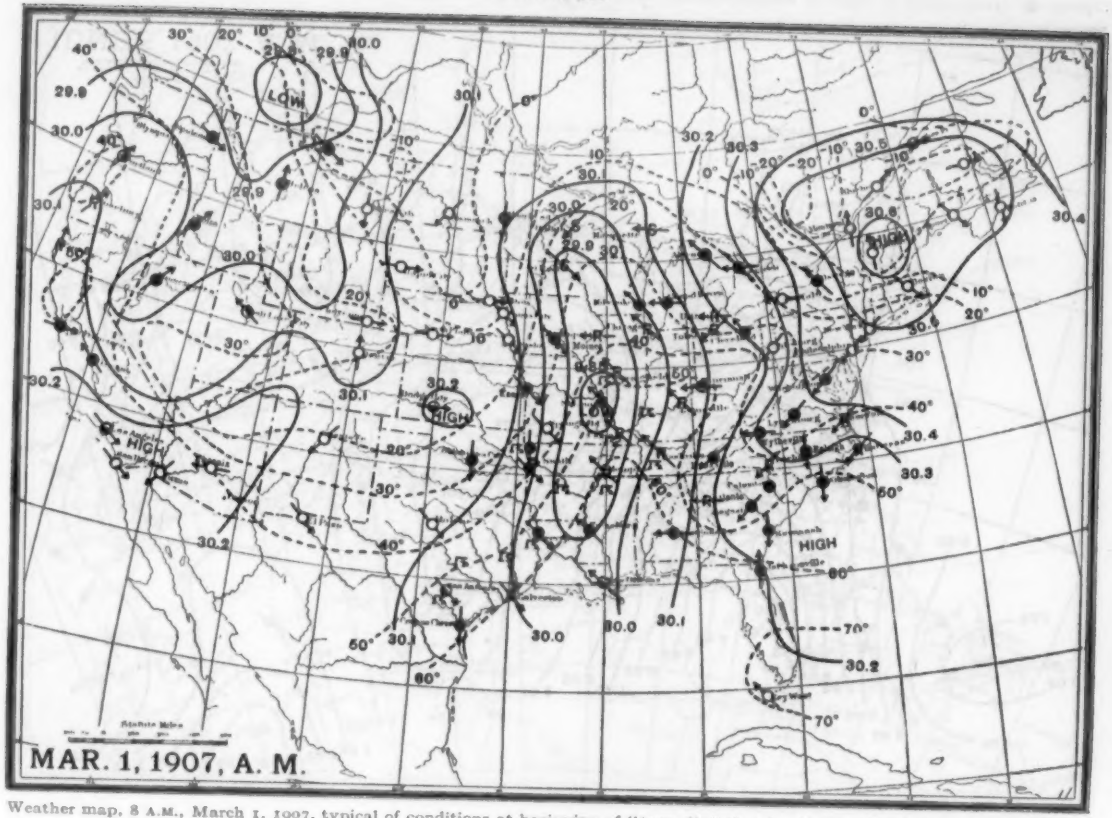
Weather map, 8 P.M., June 4, 1907, typical of "cyclonic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 10.



Weather map, 8 A.M., June 5, 1907, typical of conditions at decline of "cyclonic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

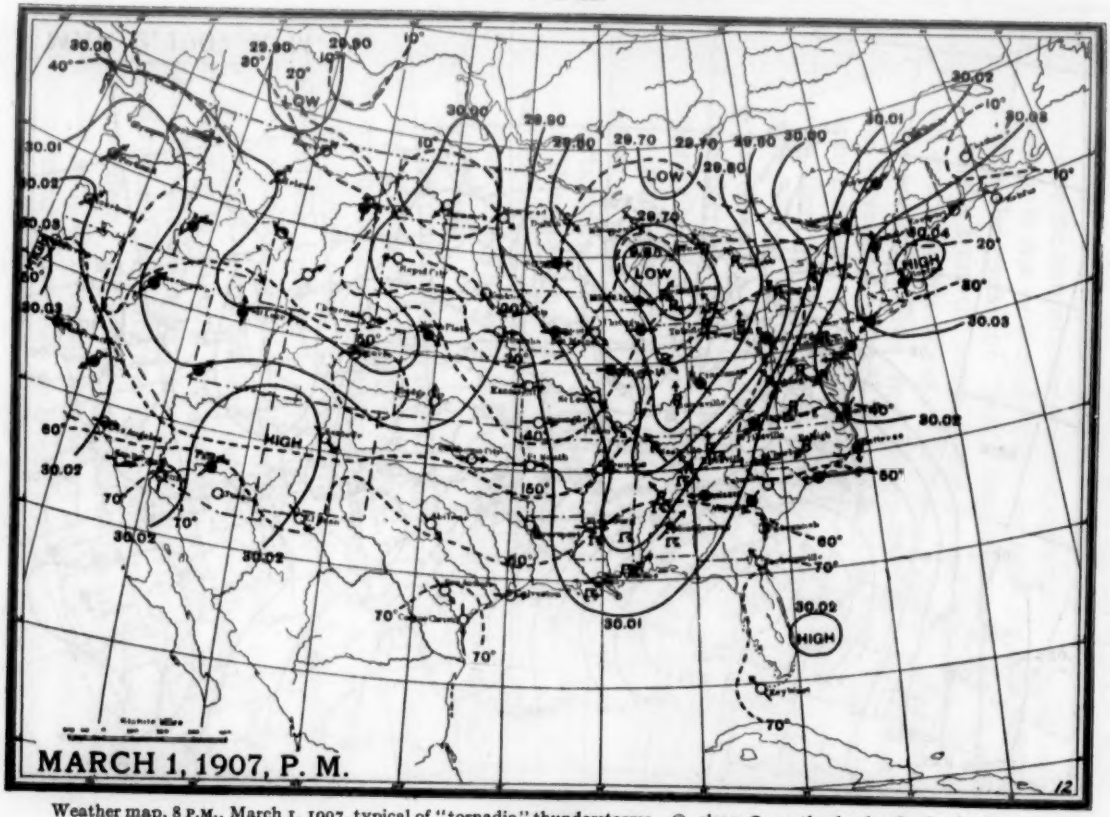
FIG. 11.



Weather map, 8 A.M., March 1, 1907, typical of conditions at beginning of "tornadic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_T, thunderstorm.

FIG. 12.

FIG. 12.



Weather map, 8 P.M., March 1, 1907, typical of "tornadic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 13.

Weather map, 8 A.M., March 2, 1907, typical of conditions at decline of "tornadic" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_t, thunderstorm.

east), or, less frequently, the southwest (Southern Hemisphere, northwest), of a regularly formed low, or typical cyclonic storm. (See Figs. 8, 9, and 10.)

In this case the temperature gradient essential to a rapid vertical convection is not produced chiefly by local surface heating, as it is during the genesis of "heat" thunderstorms, but, in great measure, results from the more or less crossed directions of the under and over currents of air. The surface air of the quadrant in question normally flows from lower and warmer latitudes, while with increasing altitude the winds come more and more nearly from the west, or even northwest. This crossing of the air currents, then, the lower from warmer sections and the upper from regions not so much warmer—possibly even colder—progessively increases the vertical temperature gradient, or rate of temperature decrease with increase of altitude, and therefore may frequently be, and doubtless often finally is, the determining cause of a rapid vertical convection and the formation of a thunderstorm.

This particular type of thunderstorm, commonly known as the "*cyclonic*" thunderstorm, is almost wholly confined to the temperate and higher zones, for the simple reason that the well-defined cyclone, essential to its creation, seldom occurs in tropical or equatorial regions.

(*c*) The barometric valley beneath the branches of a distorted or V-shaped cyclonic isobar. (See Figs. 11, 12, and 13.)

This region is also favorable to the formation of secondary lows, which, though often of small area, sometimes are intense even unto tornadic violence.

Just how specific examples of this type of pressure distribution originated may not always be clear, but however established, each necessarily leads to opposing surface winds and also to more or less oppositely directed upper currents along adjacent paths; and each wind system, the lower and the upper, tends to produce an independent effect. Thus the opposing or conflicting surface winds cause such an irregular mixing of the air and such over and underrunning of currents as is likely to establish, here and there, a convection or thunderstorm gradient. Hence the frequency of thunderstorms along the valleys of low-pressure basins. On the other hand, the oppositely directed adjacent, not conflicting, upper currents by catching masses of air, especially rising

Weather map, 8 A.M., March 2, 1907, typical of conditions at decline of "tornadic" thunderstorms. C, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_t, thunderstorm.

masses, between them tend mechanically to produce, in the middle atmosphere, violent vortices of limited extent. The more violent of these vertical atmospheric whirls, usually accompanied by thunder and rain and often extending down to the surface of the earth, where they become destructive, are known as tornadoes. Hence thunderstorms generated in the barometric region under discussion, the region in which tornadoes most frequently originate and develop, might properly be called "*tornadic*" thunderstorms.

Atmospheric conflicts and turmoil, of the nature just described, obviously may occur at any place along the protrusion, or valley, of the low-pressure basin, and therefore often do occur, even simultaneously, here and there, along its entire length, and together from the well-known "line squall." Besides, as the whole cyclonic condition moves forward in general from west to east, maintaining, in a measure, for many hours its identity of form and nature, it follows that its valley of low pressure, and therefore its line of thunderstorms, must also travel with it in the same general direction and with approximately the same velocity.

A line or row of thunderstorms—a "line squall"—as observations show, always moves across its own axis, not necessarily at right angles, but nevertheless across and not parallel to it, nor even approximately so. The chief reason for this is not the axial direction of the low-pressure valley which, indeed, though usually running south, may have any orientation from the parent basin, but rather the fact that the valley itself, together with its accompanying thunderstorm conditions, travels across and not along its own direction.

In this connection it is also worth noting that the temperature distribution in the wake of a thunderstorm renders the occurrence of an immediate successor improbable, as will be explained later. Hence, while a considerable number of thunderstorms may and often do travel abreast, they can never follow each other closely in file.

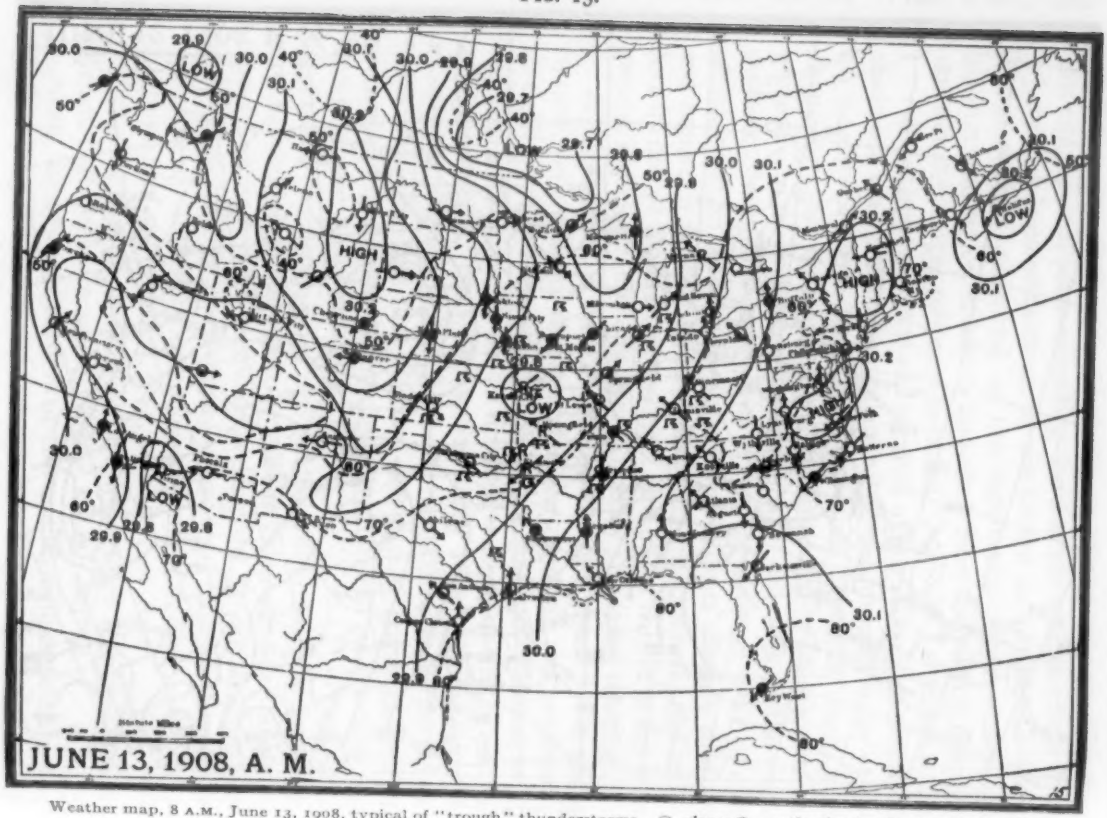
(*d*) The region covered by a low-pressure trough between adjacent high-pressure areas. (Figs. 14, 15, and 16.)

Along the adjacent borders of two neighboring anticyclones—that is, along the barometric trough between them—the surface winds from one side are more or less directly opposed to those from the other. Hence, because of the overrunning, as explained under (*c*), and the resulting temperature gradients, this also is a

FIG. 14.

Weather map, 8 P.M., June 12, 1908, typical of conditions at beginning of "trough" thunderstorms. ○, clear; ◑, partly cloudy, ●, cloudy; R, rain; R_x, thunderstorm.

FIG. 15.

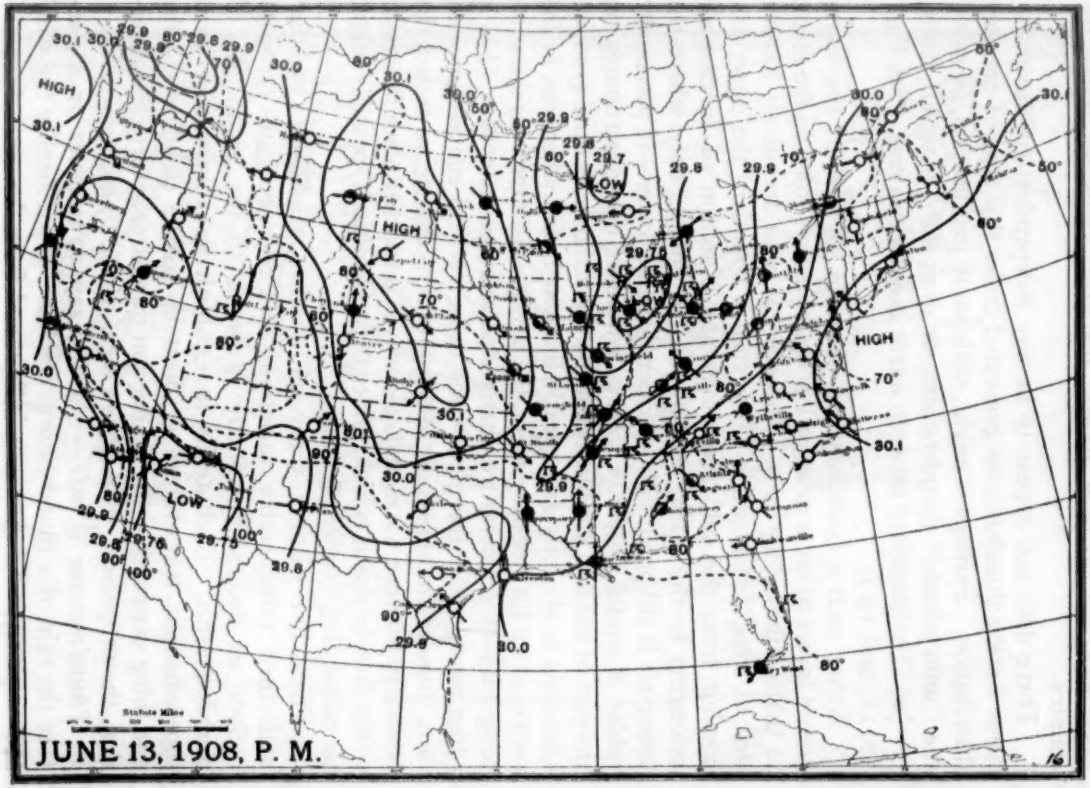


Weather map, 8 A.M., June 13, 1908, typical of "trough" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_T, thunderstorm.

FIG. 16.

Weather map, 8 A.M., June 13, 1908, typical of "trough" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

FIG. 16.



Weather map, 8 P.M., June 13, 1908, typical conditions at decline of "trough" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

region of frequent thunderstorms. Here, too, a number of more or less independent storms may exist simultaneously along the same line, and advance abreast for great distances across the country.

There does not appear to be any independent or distinctive name for the thunderstorm generated under this type of pressure distribution. Perhaps it might, with some justification, be called the "*anticyclonic*" thunderstorm, or even the "*trough*" storm.

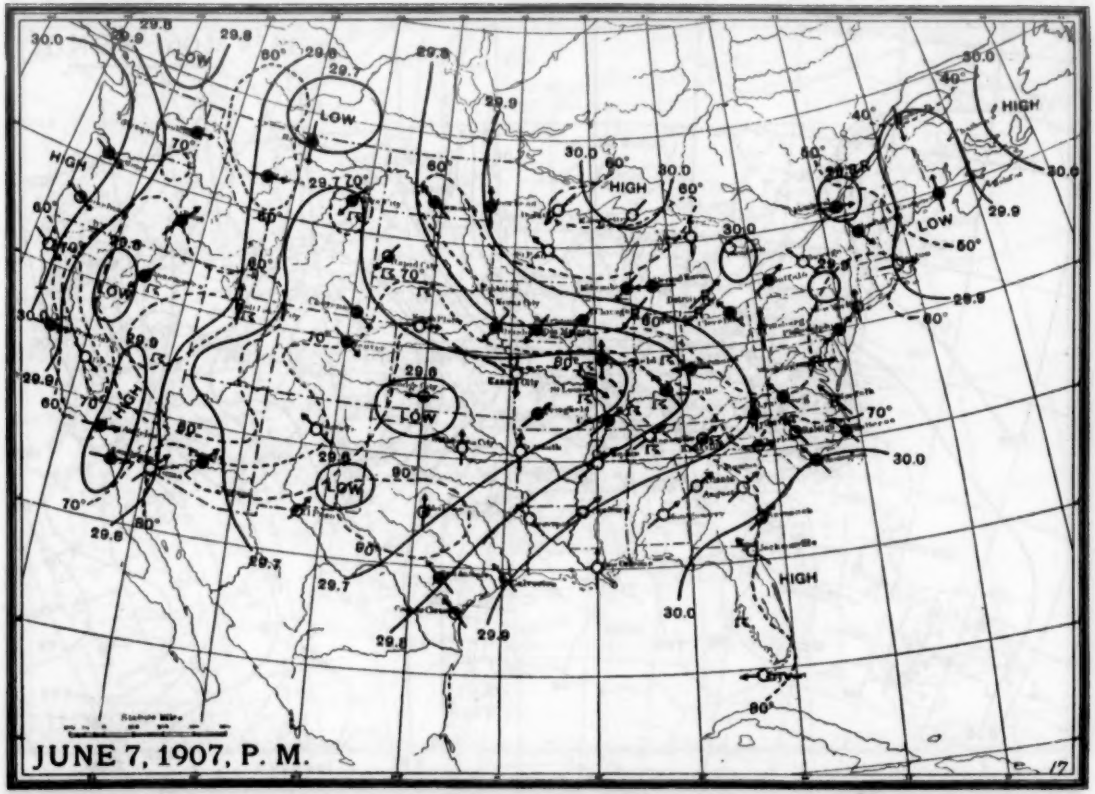
(*e*) The boundary between warm and cold waves. (See Figs. 17, 18, and 19.)

Along such a boundary the direction of flow of the warm humid layers of air is more or less opposite, as shown on the maps, to that of the colder ones. Therefore it must frequently happen that at irregular intervals along such a boundary the upper air, coming from the cold area, overruns a section of surface air belonging to the warm region; but, of course, only where the upper air is till potentially warmer than the lower—if potentially colder it would underrun. Now, wherever this overrunning on the part of the cold air does occur the vertical temperature gradient obviously is abruptly and greatly increased, and wherever, in the course of its further movement, the new gradient exceeds the adiabatic rate of temperature change, as analogous to case (*b*), it often must, under the given conditions, vertical convection with rain, thunder, and lightning is apt to occur. Hence, as stated, the boundary between warm and cold waves is another place favorable to the thunderstorm, which, under these conditions, possibly might be called the "*border*" storm.

These five distinct types of weather conditions, together with their innumerable variations and combinations, probably include all that are distinctly favorable to the production of thunderstorms. Each tends to establish an adiabatic or even superadiabatic temperature gradient up to the cloud level—the one thing essential to the production of a strong vertical convection, the progenitor, as we have seen, of the thunderstorm.

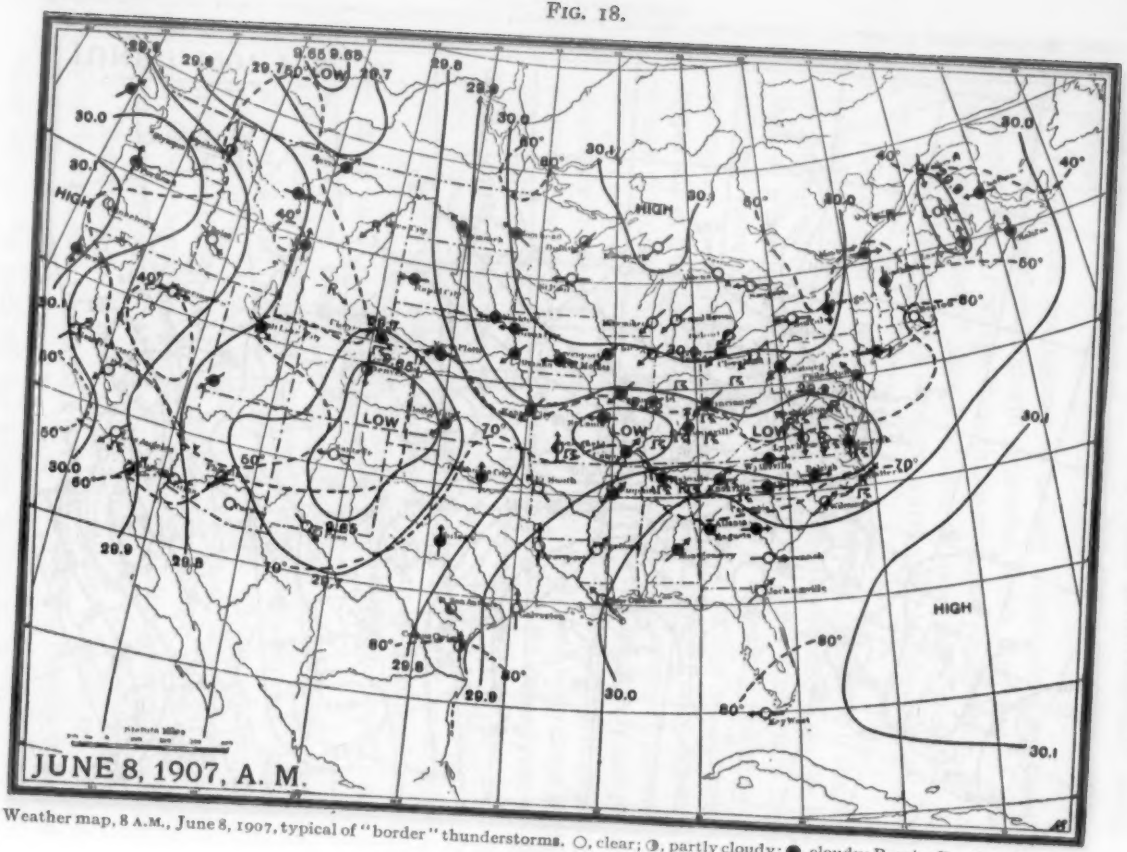
Thunderstorm Winds.—Shortly, say 20 minutes or so, before the rain of a thunderstorm reaches a given locality the wind at that place, which generally is light and from the south or southwest across the path of the storm, begins to die down to an approximate calm and to change its direction. When this change is complete, it blows for a few minutes, rather gently, directly

FIG. 17.



Weather map, 8 P.M., June 7, 1907, typical of conditions at beginning of "border" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_s, thunderstorm.

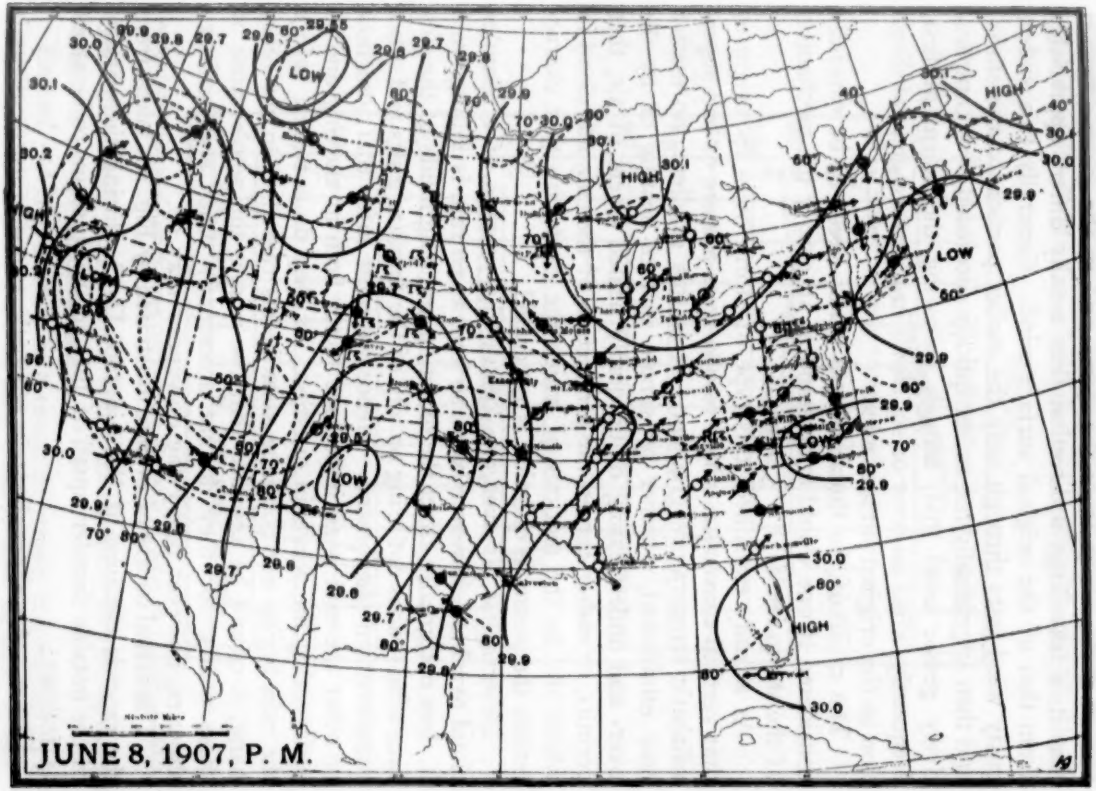
FIG. 18.



Weather map, 8 A.M., June 8, 1907, typical of "border" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R_t, thunderstorm.

FIG. 19.

FIG. 19.



Weather map, 8 P.M., June 8, 1907, typical of conditions at decline of "border" thunderstorms. ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; K, thunderstorm.

toward the nearest portion of the storm front, and finally, as the rain is almost at hand, again, but this time abruptly and in rather violent gusts, away from the storm and in the same direction that it is travelling, a direction that usually differs appreciably from that of the original surface wind. Generally this violent gusty wind lasts through only the earlier portion of the storm, and then is gradually but rather quickly succeeded by a comparatively gentle wind that, though following the storm at first, frequently, after an hour or so, blows in the same general direction as the original surface wind.

The cause of the thunderstorm winds needs to be carefully considered if one would understand at all clearly the mechanism of the storm itself.

As already explained, this type of storm owes its origin to that vertical convection which results from a more or less superadiabatic temperature gradient. It is this gradient, no matter how established, whether by simple surface heating or by the over- and underrunning of unequally heated layers of air, that permits, or rather forces, the production of the cumulus cloud in which and by the motions of which the electricity that characterizes the storm in question is generated.

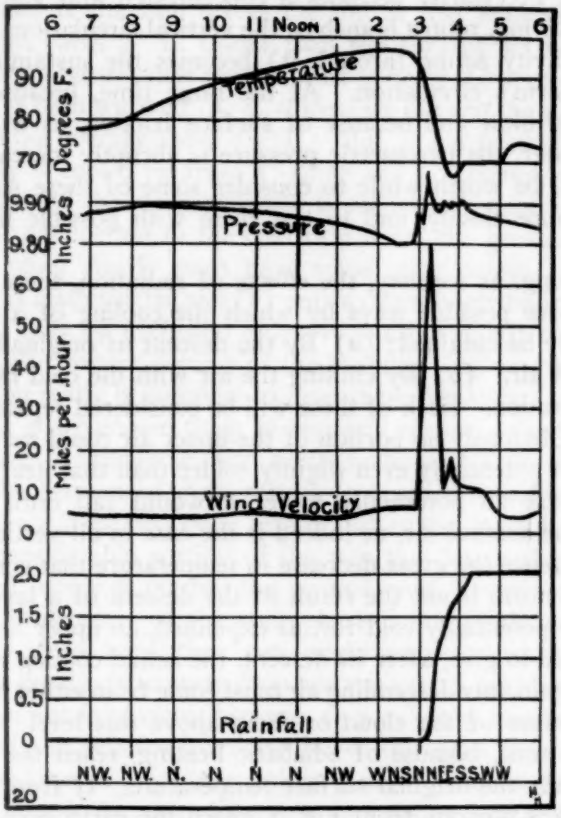
Nevertheless, as everyone knows, the passage of a cumulus cloud overhead, however large, so long as no rain is falling from it, does not greatly affect the direction and magnitude of the surface wind—does not bring on any of the familiar gusts and other thunderstorm phenomena. Hence we must infer that somehow or other the rain is an important factor both in starting and in maintaining the winds in question, for they do not exist before the rain begins nor continue after it has ceased. On the other hand, it cannot be assumed that the rain is the whole cause of these winds, for they do not accompany other and ordinary showers, however heavy the downpour may be.

The actual course of events, illustrated by Fig. 20, taken from the records obtained at Washington, D. C., during the passage of the notable thunder squall of July 30, 1913, seems to be about as follows:

First.—An approximately adiabatic temperature gradient is established over a wide area, roughly up to the base level of the cumulus clouds. But while the uprising branches of the existing convection currents, due to superadiabatic gradients, may

be localized and here and there rather rapid, the return or downflow, though really the cause of the updraft, is widespread and correspondingly gentle. The condition essential to a local and rapid downflow—that is, a local decided cooling at a high altitude

FIG. 20.



Course of meteorological elements on a thunderstorm day, at Washington, D. C. (July 30, 1913).

—does not exist, and therefore the counterpart to the upward currents is nowhere conspicuous.

Second.—After a time, as a result of strong convection in a cumulus cloud, rain is formed at a considerable altitude where, of course, the air is quite cold, in fact so cold that hail is often produced. Now this cold rain, or rain and hail, as it falls, and as long as it falls, chills the air from the level of its formation all

the way to the earth, partly as a result of its initial low temperature and partly because of the evaporation that takes place during its fall. Hence this continuously chilled column of air because, somewhat, of the frictional drag of the rain, but mainly because of the increase, due to this chilling, of its own density, immediately and necessarily becomes a concentrated and vigorous, or swiftly flowing, return branch of the vertical circulation. In fact, it (or gravity acting through it) becomes the sustaining cause of the storm's circulation. At the same time, because of the downward blow and because of surface friction, as will be explained later, the barometric pressure is abruptly increased.

It will be worth while to consider some of these statements a little more closely, and to test them with possible numerical values.

Omitting, as we may, the effects of radiation, there seem to be but three possible ways by which the cooling of a thunderstorm may be obtained: (*a*) By the descent of originally potentially cold air. (*b*) By chilling the air with the cold rain. (*c*) By evaporation. Each of these will be considered separately.

(*a*) Obviously no portion of the upper air could maintain its position if potentially even slightly colder than that near the surface. If at all potentially colder it would fall until it itself became the surface air, as indeed is the case in all vertical circulation. Hence the great decrease in temperature that comes with a thunderstorm is not the result of the descent of a layer of air originally potentially cold for, as explained, an upper layer sufficiently cold to give, after its descent, the actual cooling could not exist. Again, any descending air must come from either below the under surface of the cloud or from above this level. If from below, it must, because of adiabatic heating, reach the earth at substantially the original surface temperature. If from above it would, as is obvious from Fig. 1, reach the earth even warmer than the original surface temperature. Hence, looked at in any way, case (*a*) obviously is inadmissible.

(*b*) Let the under surface of the thunderstorm cloud be 1500 metres above the earth, and the column of air cooled by the cold rain and its evaporation 2000 metres high. Let the surface temperature be 30° C., and the temperature gradient before the storm begins adiabatic up to the under-cloud level, and let there be a 2-centimetre rainfall.

Now, at the temperature assumed, a column of air 2000 metres high whose cross-section is 1 square centimetre weighs, roughly, 210 grammes, and its heat capacity, therefore, is approximately that of 50 grammes of water. At the top of this column the temperature can be, at most, only about 20° C. lower than at the bottom, and if the rain leaves the top at this temperature but reaches the earth 7° C. colder than the surface air before the storm (temperatures that seem at least to be of the correct order) it will have been warmed 13° C. during its fall and the air column cooled on the average about 0.5° C. But, as a matter of fact, the air usually is cooled by from 5° C. to 10° C. Hence, while the temperature of the air necessarily is reduced to some extent by mere heat conduction to the cold rain much the greater portion of the cooling clearly must have some other origin. Further, since (*a*) is inadmissible and (*b*) only a minor contributing factor, it follows that by exclusion only evaporation is left to account for much the greater portion of the cooling. Let us see, then, if evaporation really is adequate to meet these demands.

(*c*) It is a common thing in semiarid regions to see a heavy shower, even a thundershower, leave the base of a cloud and yet fail utterly, because of evaporation, to reach the surface of the earth. Hence it appears quite certain that in the average thunderstorm a considerable portion of the rain that leaves the cloud is evaporated before it reaches the ground, and therefore that the temperature decrease of the atmosphere is largely owing to this fact. But if so, why, then, one might properly ask, does not an equally great temperature drop accompany all heavy rains?

The answer is obvious, because, as a rule, the temperature is higher and the relative humidity lower during a thunderstorm than at the time of any other ordinary rain. The chief, perhaps the sole, reason for this difference in relative humidity is the difference in the two cases between the movements of the air. In the thunderstorm the descending air, which can be no more than saturated at top, dynamically warms so rapidly and is so continuously renewed that evaporation into it cannot keep pace with its vapor capacity. During other rains, however, where there is no atmospheric descent, and therefore no dynamical heating, approximate saturation must soon obtain; hence but little further evaporation and, of course, but little cooling.

We will now return to the numerical values and compute a probable magnitude of cooling due to evaporation.

As before, let a 2-centimetre rain leave the cloud, but let one-fourth of the rain that started, or half a centimetre, be evaporated. This would consume 303 heat units from an air column 2000 metres high whose heat capacity is that of only 50 cubic centimetres of water. Hence, as a result of evaporation alone, the temperature of the air column would be lowered on the average by about 6° C. Evaporation, therefore, appears to be both necessary and sufficient to produce all or nearly all the cooling of a thunderstorm.

Since the molecular weight of water is 18, while the average molecular weight of air is approximately 29, it follows that the amount of evaporation above assumed would decrease the density of the atmosphere by, roughly, one part in a thousand. On the other hand, a decrease in temperature of 6° C., that would be produced by the evaporation assumed, would increase the density by about one part in fifty. Hence the resultant of these two opposing effects is substantially that of the second alone; that is, a distinct increase in the density.

Doubtless, as already stated, the evaporation of thunderstorm rain, and therefore the drop in temperature and the consequent gain in density, all increase with decrease of elevation. In some measure, however, this effect is counteracted by the increasing rate of dynamical heating in the lower layers resulting from the correspondingly increased rate of pressure gain to change in elevation.

But no matter how or to what extent the details may vary, it seems quite certain that the cold rain of a thunderstorm and its evaporation together must establish a local downrush of cold air—an observed important and characteristic phenomenon, really the immediate cause of the vigorous circulation, whose rational explanation has been attempted in the last few paragraphs.

As the column or sheet of cold air flows down it maintains in great measure its original velocity and, therefore, on reaching the earth rushes forward in the direction of the storm movement, underrunning and buoying up the adjacent warm air. And this condition—largely due, as explained, to condensation and evaporation—once established is necessarily self-perpetuating, so long as the general temperature gradient, humidity, and wind

direction are favorable. It must be remembered, however, that thunderstorm convection, rising air just in front and descending air with the rain, does not occur in a closed circuit, for the air that goes up does not return nor does the air that comes down immediately go up again; there simply is an interchange between the surface air in front of the storm and the upper air in its rear. The travel of the storm, by keeping up with the underrunning cold current, just as effectually maintains the temperature contrast essential to this open-circuit convection as does continuous heating on one side and cooling on the other maintain the temperature contrast essential to a closed circuit convection.

The movements of the warm air in front of the rain, the lull, the inflow, and the updraft resemble somewhat those of a horizontal cylinder resting on the earth where the air is quiet and rolling forward with the speed of the storm. Similarly, the cold air in its descent and forward rush, together with the updraft of warm air, also resembles a horizontal cylinder, but one sliding on the earth and turning in the opposite direction from that of the forward-rolling or all-warm cylinder. In neither case, however, is the analogy complete, for, as above explained, the air that goes up remains aloft while the cold air that comes down is kept by its greater density to the lower levels. The condition of flow persists, as do cataracts and crest clouds, but here, too, as in their case, the material involved is ever renewed.

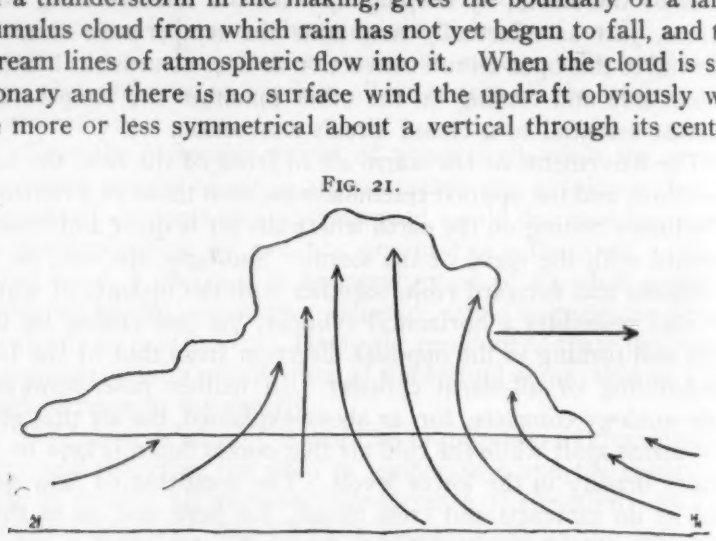
The Squall Cloud.—Between the uprising sheet of warm air and the adjacent descending sheet of cold air horizontal vortices are sure to be formed in which the two currents are more or less mixed. The lower of these vortices can only be *inferred* as a necessary consequence of the opposite directions of flow of the adjacent sheets of warm and cold air, for there is nothing to render them visible. Neither can any vortices that may exist within the cloud be seen. Near the front lower edge of the cumulo-nimbus system, however, and immediately in front of the sheet of rain, or rain and hail, the rising air has so nearly reached its dew point that the somewhat lower temperature, produced by the admixture of the descending cold air, is sufficient to produce in it a light fog-like condensation which, of course, renders any detached vortex at this position quite visible.

This squall cloud, in which the direction of motion on top is

against the storm, may be regarded as a third horizontal thunderstorm cylinder much smaller but more complete than either of the others.

Schematic Illustrations.—The above conceptions of the mechanism of a thunderstorm can, perhaps, be made a little clearer with the aid of illustrations. Fig. 21, a schematic picture of a thunderstorm in the making, gives the boundary of a large cumulus cloud from which rain has not yet begun to fall, and the stream lines of atmospheric flow into it. When the cloud is stationary and there is no surface wind the updraft obviously will be more or less symmetrical about a vertical through its centre,

FIG. 21.



Principal air movements in the development of a cumulus cloud.

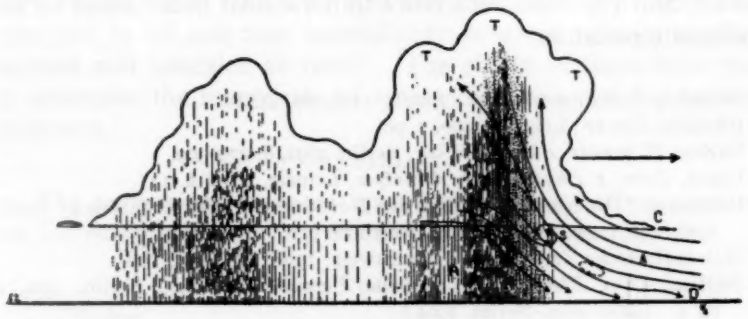
but when it has an appreciable velocity, as indicated in the figure, it is equally obvious that most, often nearly all, of the air entering the cloud will do so through its front under-surface. At this stage there will be no concentrated or local down current, only an imperceptible counter settling of the air round about, because, as previously explained, the air cataract requires local cooling to subpotential temperatures, and this in turn requires local rain.

Fig. 22 schematically represents a well-developed thunderstorm in progress. The falling rain, often mixed with hail, cools the air through which it falls, and as the temperature gradient was already closely adiabatic it follows that the actual temperatures will be subpotential from the surface of the earth to within the cloud, or throughout and a little beyond the non-saturated or evaporating levels. As soon, then, as this column or sheet of

air is sufficiently cooled it flows down and forward and all the atmospheric movements peculiar to the thunderstorm are established substantially as shown.

Referring to the figure: The warm ascending air is in the region *A;* the cold descending air at *D;* the dust cloud (in dry weather) at *D'*; the squall cloud at *S;* the storm collar at *C;* the thunder heads at *T;* the hail at *H;* the primary rain, due to initial convection, at *R;* and the secondary at *R'*. This latter phenomenon, the secondary rain, is a thing of frequent occurrence and often is due, as indicated in the figure, to the coalescence

FIG. 22.



Ideal cross-section of a typical thunderstorm. *A*, ascending air; *D*, descending air; *C*, storm collar (*Sturmkragen*); *S*, roll scud; *D'*, wind gust; *H*, hail; *T*, thunderheads; *R*, primary rain; *R'*, secondary rain.

and quiet settling of drops from an abandoned portion of the cumulus in which and below which winds and convection are no longer active.

Mammato-cumuli rarely, false cirri frequently, and cap-clouds occasionally, accompany thunderstorms, but as they are not essential to it they therefore are omitted from the above schematic illustration.

Thunderstorm Pressures.—Before the onset of a thunderstorm there usually if not always is a distinct fall in the barometer. At times this fall is extended over several hours, but whether the period be long or short the rate of fall usually is greatest at the near approach of the storm. Just as the storm breaks, however, the pressure rises very rapidly, almost abruptly, usually from 1 to 2 millimetres, fluctuates irregularly, and finally as the

storm passes again becomes rather steady but at a somewhat higher pressure than prevailed before the storm began.

The cause of these pressure changes is, doubtless, rather complex. The decrease in the absolute humidity and the decrease in temperature both tend to increase the atmospheric pressure, and, presumably, each contributes its share. Both these effects, however, are comparatively permanent, and while they may be mainly responsible for the increase of pressure that persists after the storm has gone by, they probably are not the chief factors in the production of the initial and quickly produced pressure maximum. Here at least two factors, one obvious, the other inconspicuous, are involved. These are: (*a*) The rapid downrush of air, and (*b*) the interference to horizontal flow caused by the vertical circulation.

[1] Memoirs, Indian met'l. dept., Simla, 1910, **20**, pt. 8.
[2] *Physikal. Ztschr.*, Leipzig, 1906, **7**, 98.
[3] Sitzber, *K. preuss. Akad. d. Wiss.*, Berlin, 1892, **8**, 279–309.
[4] Braak, *Beitr. z. Physik d. fr. Atmosph.*, Leipzig, 1914, **6**, 141.
[5] Hellmann, "Die Niederschläge in den Norddeutschen Stromgebieten," Berlin, 1906, vol. 1, pp. 336–337, and elsewhere.
[6] *Meteorologische Zeitschrift*, Braunchweig, 1908, **25**, Jhrg., 108.
[7] Steffens, Otto, *Ztschr. f. d. gesamte Versicherungswiss.*, Berlin, 1904, 4, pt. 4. (Also Diss.-Berlin, 1904.)
[8] Humphreys, W. J., Bull., Mt. Weather Obs'y, Washington, 1913, **6**, 1.

(*To be concluded in December.*)

Belgian Blast Furnaces. ANON. (*Eng.*, xcvii, No. 2529, 859.)—The number of furnaces in blast in Belgium and in the Luxembourg at the beginning of June was 49, as compared with 52 at the beginning of June, 1913. The number of furnaces out of blast at the commencement of June, 1914, was 11, as compared with three on the corresponding period of 1913. The 49 furnaces in blast at the beginning of June were distributed as follows: Hainaut and Brabant, 24; Liège group, 18; Luxembourg, 7. The production of pig iron in Belgium and the Luxembourg in May was 215,020 tons, as compared with 224,550 tons in May, 1913, while in the five months ended May 31, this year, the aggregate output was 1,029,050 tons, as compared with 1,007,760 tons in the corresponding period of 1913. The total of 1,029,050 tons representing this year's aggregate output was made up as follows: Puddling pig, 21,020 tons; casting pig, 40,320 tons; and steel pig, 967,710 tons.

INTERNAL STRESSES IN HEAT-TREATED AXLES.*

BY

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A SERIES of experiments was conducted upon two 10" driving axles about six feet long for the purpose of determining the internal stresses in forgings after heat treatment. The axles were hollow bored with a 3" hole and were heated to 1500° and quenched in oil and then immediately removed to an annealing furnace and annealed at 1200°. The object of these tests was to determine the magnitude of stresses in the axles due to heat treatment.

MATERIAL.

The axles were made of open hearth plain carbon steel of the following chemical analysis and physical properties.

HEAT NUMBER 71429.

Carbon	.50
Manganese	.44
Phosphorus	.037
Sulphur	.038
Elastic limit	54000
Tensile strength	88500
Elongation in 2"	24 %
Reduction of area	43.5%

The axles were made from blooms of the same size and were given the same reduction and number of heats in forging.

HEAT TREATMENT.

Both axles were heated to the same temperature for quenching and drawing back and were held in the furnace the same length of time for these operations; both were quenched in the same oil tank, the *difference* in the *treatment* being the *method*

* Communicated by the Author.

of quenching. One axle was lowered *horizontally,* the other *vertically,* into the oil.

The heating temperatures for both axles were as follows:

(1) *Heated* to 1600° F., allowing six hours for the temperature to rise to this point and held at this temperature for another six hours.

(2) *Quenched* in oil until practically cold.

(3) *Drawn* at 1200° F., allowing, as before, six hours to come to this temperature, and held at this temperature for six hours. *Removed from furnace* and allowed to cool naturally in the air inside the hammer shop.

DESIGNATION OF AXLES.

The axle which had been quenched horizontally was marked "H."

The axle which had been quenched vertically was marked "V."

PORTIONS EXPERIMENTED UPON.

Each axle was cut in half at the works of the manufacturer, after heat treatment, one-half being cut up into tensile test specimens, and the other half reserved for these experiments.

The end of axle "V" that went into the oil first was employed for making these experiments.

METHODS OF TEST.

The strains in certain portions of the axle (see Fig. 1) were obtained by carefully measuring specimens before and after their removal from the axles. The stresses were calculated from the measured strains.

Two methods, (*a*) and (*b*), hereafter described, were used to obtain the strains:

(*a*) The measurement of rings cut from cross-sections of the forgings.

(*b*) The measurement of straight pieces taken out of the axles in three directions: tangentially, radially, and parallel to the axis of the forgings.

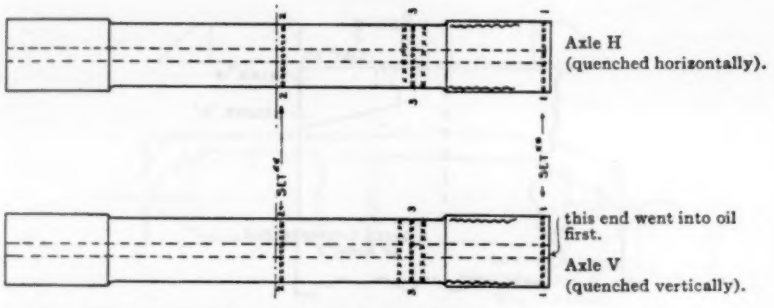
Method (*a*).—This method, which was used at the Watertown Arsenal some years ago by the Ordnance Department,

U. S. A., for the determination of stresses in gun forgings, is as follows:

Concentric rings are removed from the forgings and their diameters and thicknesses measured on several points, before and after removal. From the diameters and thicknesses of attached rings the mean diameter can be found, and from the diameters and thicknesses of the rings after removal their mean diameter is again found, and from the differences between these results before and after removal, assuming that the rings remain circular, the strains and stresses are calculated. The special application of this method to our experiments was as follows:

(1) Four rings were removed at each of the three sections, 1,

FIG. 1.



2, and 3, shown in Fig. 1. The rings taken out at each section were known as sets: set No. 1 coming from the end of the wheel-fit; set No. 2 coming from what was approximately the middle of the axle; and set No. 3 midway between 1 and 2.

Each of the rings was numbered, starting with the smallest ring as No. 1, and were removed as follows: The axles were turned cylindrically for a short distance and four diameters of this cylindrical portion, 45° apart, were measured with outside micrometer calipers (these measurements being known as "original values").

(2) A concentric groove "G" (see Fig. 2) was cut, and the same four diameters again measured (these measurements were known as "attached values").

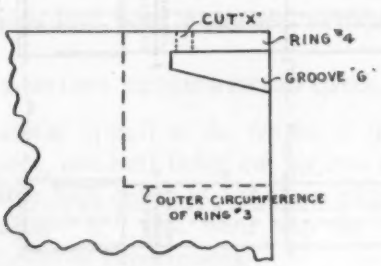
(3) A ring was removed by cutting off at "X" (Fig. 2), and the same diameters measured again (these measurements known as "detached values").

(4) The thickness of the rings was measured at the end of each of these diameters, and from these measurements the mean diameter of the ring was determined, for the "attached" and "detached" values.

Generally the mean diameters of the rings at the four points were found to be larger after removal than before, but in a number of cases this was not true, indicating that the ring did not remain circular but assumed some shape which it was not possible to plot from the measurements of diameters.

After the outside (the No. 4) ring had been removed, the axle was turned down to the outer diameter of the next (the

FIG. 2.



Method of removing rings.

No. 3) ring, and the process of measuring repeated. In this manner twelve rings were removed from each axle. (See Figs. 1, 2, and 5*a*.)

From all of these measurements it was expected to average the strains and calculate the stresses released by the undercutting and removal of the rings.

Method (*b*).—The measurement of changes in length of specimens by means of a comparator is a standard and one used extensively, but the method developed here by measuring small changes in length by means of one microscope and a *standard of comparison* has not been used before, so far as I know. The use of the comparator for a purpose similar to our investigation is described in "The International Proceedings of Metallography" (January 16, 1911), by Professors Heyn and Bauer.

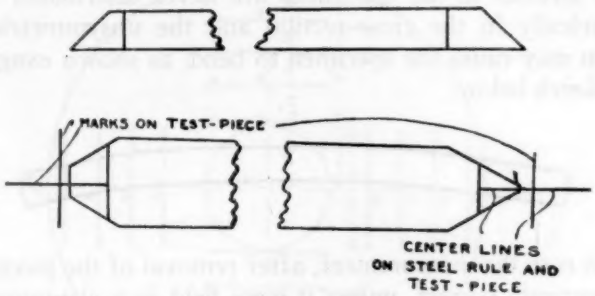
The use of a *standard of comparison* of 15 inches or more in length would probably enable one to realize a degree of accuracy as high as that obtained by Professors Heyn and Bauer with a comparator.

The measurement of straight specimens under this method is as follows:

Specimens are laid out on a smoothly finished surface and marks made on them along the ends of a hardened steel scale of a definite length by means of a very fine scriber.

A *standard of comparison,* slightly shorter than the steel scale and made of the same material as specimens to be measured and shaped, as shown in Fig. 3, is placed between the marks on the specimens.

FIG. 3.



Standard of comparison.

A microscope with Filar micrometer attachment is focused on the end of the specimen, and the distance between each end of the *standard of comparison* and the marks on the test piece is measured before the specimen is cut out.

In addition to the marks perpendicular to the axis of the specimen a line is drawn parallel to the axis, and there are also longitudinal marks on the ends of the *standard of comparison,* which, in measuring, are placed on the longitudinal line of the specimen, in order to always have it in the same position with respect to the axis of the specimen to be measured.

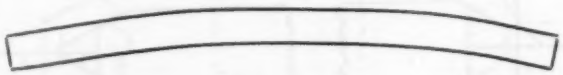
After the specimen is removed the *standard of comparison* is again placed on it and the operation of measuring is repeated. It makes no difference whether the *standard* is in the same posi-

tion with respect to the end marks as it was before or not, for the reason that the total distance between the ends of the *standard* and the marks is what we are considering, and the difference between the measurements before and after cutting out is the strain in a specimen of a length equal to the original distance between the marks, assuming of course that the length of the *standard of comparison* is the same in each measurement.

For this reason, the *standard* should be made, as noted above, of the same material as the part to be measured in order to avoid complications which would arise due to differences in temperature.

All of the measurements in our experiments were made at as nearly as possible the same temperature, and precautions were taken to minimize changes in temperature during the measurements.

The stresses in the specimens are never distributed entirely symmetrically in the cross-section and the unsymmetrical distribution may cause the specimen to bend, as shown exaggerated in the sketch below,



in which case the measurement, after removal of the piece, would not be entirely correct, unless it were held in a clamping device which would keep it straight. If such a device is not used, the amount of the bend must be measured and correction made for the shortening of the specimen. Such device was not found necessary in these experiments, as there was no bending that could be noticed at all in any of the specimens, with the exception of the longitudinal pieces cut from the inside of each axle (see Fig. 5—the cross hatch portion next the hole). These results have been corrected for this condition. The probable error of measurement made by the method above described, using a magnification of fifty diameters, is about one ten-thousandth of an inch.

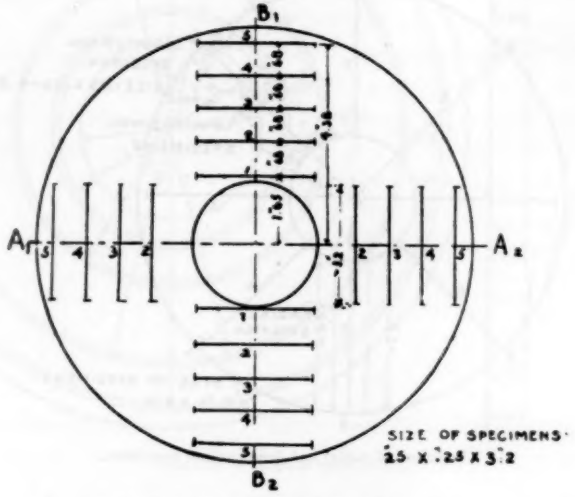
The results of our experiments under method (*b*), which are given in the following tables and curves, are based on measurements of fifty test pieces from each axle, as follows:

18 Tangential specimens (see Fig. 4).
8 Radial specimens (see Fig. 5).
24 Longitudinal specimens (see Fig. 5), parallel to the axis on points 1 to 8; 8 pieces from the circumference, 8 pieces from the middle, and 8 from near the circumference of the hole.

Removal of Specimens.—The specimens to be measured under method (*b*) were selected and removed as follows:

The tangential and radial specimens were laid out on a smooth surface perpendicular to the axis of each axle and marked, as described, with an extremely sharp scriber along the ends of the hardened steel scale.

FIG. 4.



Location of tangential specimen.

A disk of about ¾ of an inch was then cut from the marked end of the axle and planed down to a thickness of about 5/16 of an inch in the case of the disk containing the tangential specimens, and to a thickness of .4 of an inch in the case of the disk containing the radial specimens, which were removed after the tangential specimens had been cut out. The reason for increasing the thickness of the disk was to facilitate the machining.

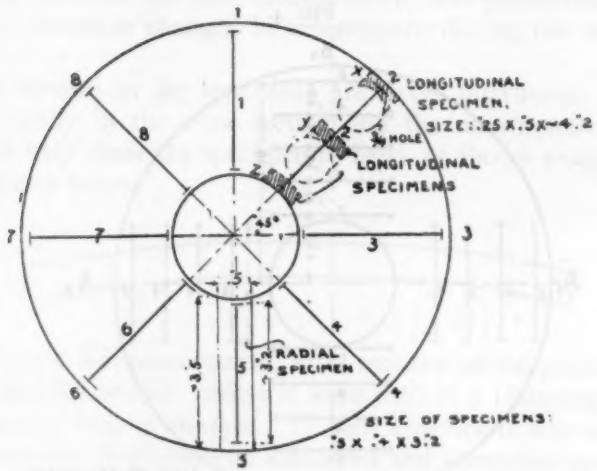
The first set of tangential specimens were cut out on a shaper, but as this was found to be an unsatisfactory method, several

specimens, namely, B 1-1 and A 1-5 being spoiled, all of the other test pieces were cut out on the miller.

It was found impossible to remove tangential pieces A1-1 or A 2-1 from either axle on account of a lack of space. (See Figs. 4 and 5 for location of specimens.)

In removing the longitudinal test pieces, the holes in the axles were bored out slightly larger (trued up) and the circumferences of the axles and of the holes in the axles were ground cylindrically for a distance of about 8 inches. The specimens were laid out first on the outside of this cylindrical portion and measured as

FIG. 5.



Location of radial and longitudinal specimen.

described above, using a longer scale and *standard of comparison.* Three-quarter-inch holes were then drilled parallel to the axis (see Fig. 5) and the pieces milled out.

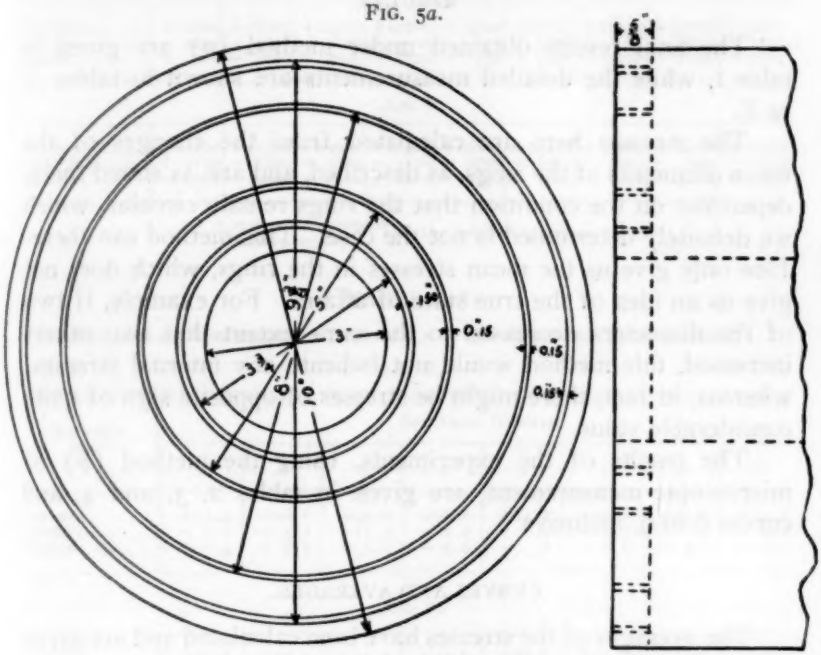
The remainder of the axle was then turned down to the diameter midway between the original outside diameter and the diameter of the hole and the operation repeated for the longitudinal specimens midway between the centre and the outside. The longitudinal specimens from the inside were obtained in the same manner.

In all cases, after removal, the specimens were brought to the Test Department and placed with the *standard of comparison*

and the steel scale and allowed to come to the same temperature. They were handled with woollen gloves and every precaution taken to maintain them at the same temperature.

Below is shown the method of calculating the strains and stresses and the results of the tests:

FIG. 5*a*.



Position of rings in method (*a*).

Calibration of Filar Micrometer.—Using a 32 mm. objective and a glass scale with divisions of .01 of a millimetre, it was found that one interval of the drum of the Filar micrometer is equal to .0002215 mm., or .0000872 of an inch. (Personal value of E. Vogt.)

Calculations.—For a distance of 1 cm. between the marks the stresses expressed in Kg./cm. Sq./ 467.2 *i*.

Where *i* is the strain of specimens expressed in intervals of the drum of Filar micrometer, from which

$$\text{Lbs./Sq. in.} = 6645 \times i$$

and the stress in the distance measured is

$$\text{Lbs./Sq. in.} = \frac{6645 \times i}{n}$$

where n = original distance in cm. between the marks on the specimens.

RESULTS.

The final results obtained under method (*a*) are given in table 1, while the detailed measurements are shown in tables A to E.

The stresses here are calculated from the changes of the mean diameters of the rings, as described, and are, as stated there, dependent on the condition that the rings remain circular, which we definitely determined is not the case. This method can therefore only give us the mean stresses in the rings, which does not give us an idea of the true state of affairs. For example, if two of the diameters decreased to the same extent that two others increased, this method would not indicate any internal stresses; whereas, in fact, there might be stresses of opposite sign of quite considerable value.

The results of the experiments, using the method (*b*) of microscopic measurement, are given in tables 2, 3, and 4, and curves 6 to 9, inclusive.

CURVES AND AVERAGES.

The averages of the stresses have been calculated and are given in the tables following.

TABLE 1.[1]

Ring No.	Mean of stresses, as calculated from mean strain in detached ring of set No.							
	1		2		3		Mean	
	Axle H	Axle V	Axle H	Axle V	Axle H	Axle V	Axle H	Axle V
1	27250	40550	30200	29800	24900	23700	27450	31350
2	12580	14700	37300	9810	16260	15560	22047	13357
3	12100	3100	8730	17220	13200	9480	11343	9933
4	21800	8460	20280	23050	17900	18880	19993	16797
Mean	18433	16703	24128	19970	18065	16905	20208	17859

[1] All in compression.

TABLE 2.

STRESSES AND STRAINS IN LONGITUDINAL SPECIMENS AS PER FIGS. 1 AND 5.

Axle H.

Location of set	Specimen Number.								Mean
	1	2	3	4	5	6	7	8	
Outside.....	+14600	+18500	+24900	+22800	+ 9200	+16700	+27300	+19700	+19210
Middle.....	− 4500	+ 2900	− 7100	− 4000	− 200	+ 1200	− 60	− 2600	− 1862.5
Inside.....	+ 900	− 3800	− 3800	− 2900	− 500	− 5500	− 2900	− 1700	− 2525

Axle V.

Outside.....	+11100	+17700	+10600	+15300	+16100	+13400	+16400	+ 6400	+13375
Middle.....	+ 1700	− 300	− 2400	− 3200	− 6800	− 5500	− 3200	− 900	− 2575
Inside.....	− 6500	− 6100	− 8700	− 2400	− 3700	− 7000	− 6700	− 5100	− 5775

+ means compression
− means tension
} in the original specimen.

TABLE 2-A.

STRAINS OF SPECIMENS IN INTERVALS OF DRUM AS PER FIGS. 1 AND 5.

Axle H.

Location of set	Specimen Number.							
	1	2	3	4	5	6	7	8
Outside.....	+23.4	+29.7	+40.0	+36.6	+14.8	+26.8	−43.9	+31.7
Middle.....	− 7.2	+ 4.7	−11.4	− 6.4	− .3	+ 1.9	− .1	− 4.2
Inside.....	+ 1.4	− 6.1	− 6.1	− 4.6	− .8	− 8.8	− 4.7	− 2.7

Axle V.

Outside.....	+17.8	+28.4	+17.0	+24.6	+25.8	+21.5	+26.3	+10.3
Middle.....	+ 2.7	− .5	− 3.8	− 5.1	−10.9	− 8.8	− 5.1	− 1.4
Inside.....	−10.4	− 9.8	−13.9	− 4.0	− 5.9	−11.3	−10.7	− 8.2

m = No. of cm. between original marks on specimens = 10.67.

TABLE 3.

STRESSES OF RADIAL SPECIMENS DISTRIBUTED EQUALLY AROUND THE AXIS BY 45°, AS PER FIGS. 1 AND 5.

Axle	Specimen Number.								
	1	2	3	4	5	6	7	8	Average
H	+11900	+10200	+ 7300	+ 6900	+12200	−10400	− 2400	+10000	+ 5713
V	+ 4600	+ 9400	+14700	+13900	+15500	+13400	+ 5300	+16500	+11663

TABLE 3-A.

STRAINS OF RADIAL SPECIMENS, AS PER FIG. 5, IN INTERVALS ON DRUM OF FILAR MICROMETER.

Axle	Specimen Number.							
	1	2	3	4	5	6	7	8
H	+14.2	+12.2	+ 8.7	+ 8.3	+14.6	−12.4	− 2.9	+12.0
V	+ 5.5	+11.2	+17.6	+16.6	+18.5	+16.0	+ 6.3	+19.7

n = number of cm. between original marks on specimens = 7.97.

TABLE 4.

STRESSES IN POUNDS PER SQUARE INCH OF THE TANGENTIAL SPECIMENS, AS PER FIGS. 1 AND 4.

No. of specimen.	Axle H					Axle V				
	A1	A2	B1	B2	Average	A1	A2	B1	B2	Average
1	.....	.....	*	+ 5300	+ 5300	.....	.....	+27300	+18800	+23050
2	+ 2700	+ 6500	+ 2500	− 1500	+ 2550	− 1100	+ 900	+ 7000	+ 7300	+ 3525
3	+ 9400	+10500	− 900	− 3500	+ 3875	+ 8400	−12100	+ 3300	+ 1400	+ 250
4	+ 8400	+10600	+ 8500	+ 5600	+ 8275	+17700	+ 5500	+10000	+ 3100	+ 9750
5	*	+12300	+17400	+18600	+16100	+29200	+21400	+28500	+28700	+27450
Average.	+ 6833	+ 9975	+ 6875	+ 4900	+ 7183	+13550	+ 3925	+15220	+11860	+11972

* Specimen spoiled during cutting operations in the shop.
\+ Compression in the original specimen.
− Tension in the original specimen.

TABLE 4-A.

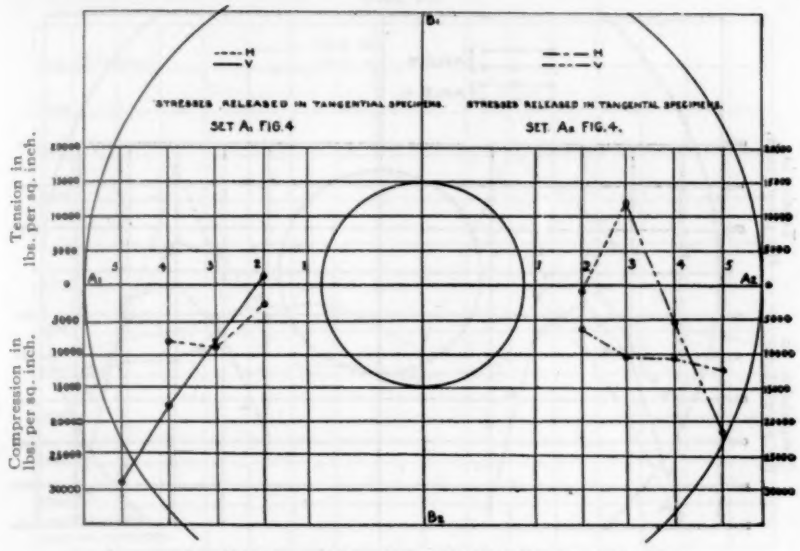
STRAINS OF THE TANGENTIAL SPECIMENS, AS PER FIG. 4, IN INTERVALS ON DRUM OF FILAR MICROMETER.

No. of specimen	Axle H (n = 7.97).				Axle V (n = 7.66).			
	A1	A2	B1	B2	A1	A2	B1	B2
1	....	....	....	6.3	....	....	+31.5	+21.6
2	+ 3.2	+ 7.8	+ 3.0	− 1.8	− 1.3	+ 1.0	+ 8.1	+ 8.4
3	+11.2	+12.6	− 1.1	− 4.2	+ 9.7	−13.9	+ 3.8	+ 1.6
4	+10.1	+12.7	+10.2	+ 6.7	+20.4	+ 6.3	+11.5	+11.3
5	....	+14.7	+20.8	+22.3	+33.7	+24.7	+32.8	+33.1

n = number of cm. between original marks on specimens = 7.97.

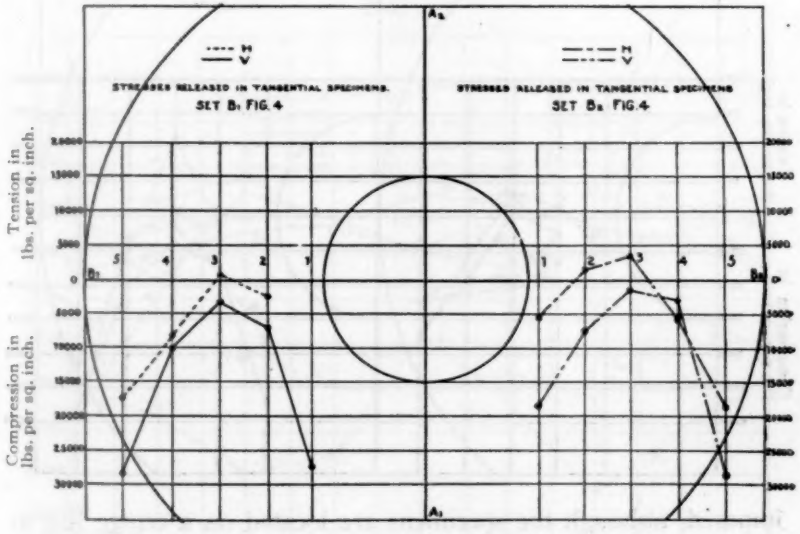
Fig. 6 shows the stresses released in the tangential specimens, plotted on the diameter A-1 A-2 (Fig. 4); Fig. 7 shows the stresses released in the tangential specimens, plotted on the diameter B-1 B-2 (Fig. 4); Fig. 8 shows these two curves super-

FIG. 6.



Stresses released in tangential specimen plotted in diameter A_1 A_2, Fig. 4.

FIG. 7.



Stresses released in tangential specimen plotted in diameter B_1 B_2, Fig. 4.

FIG. 8.

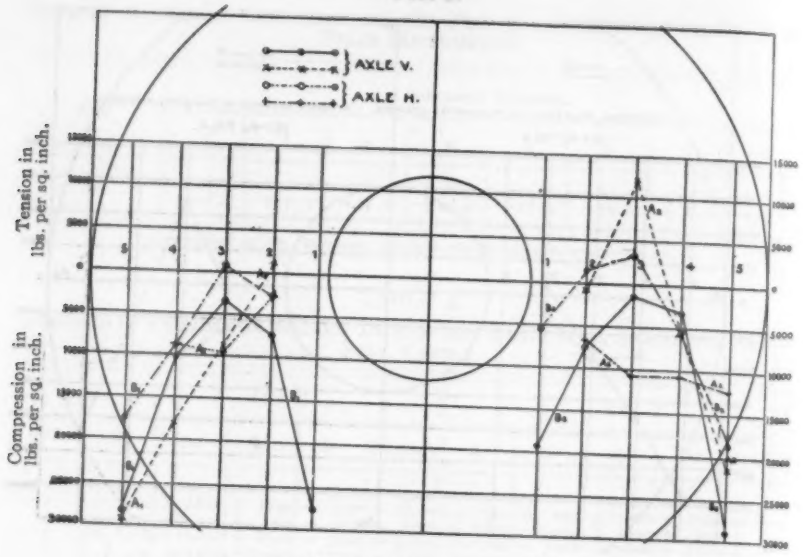
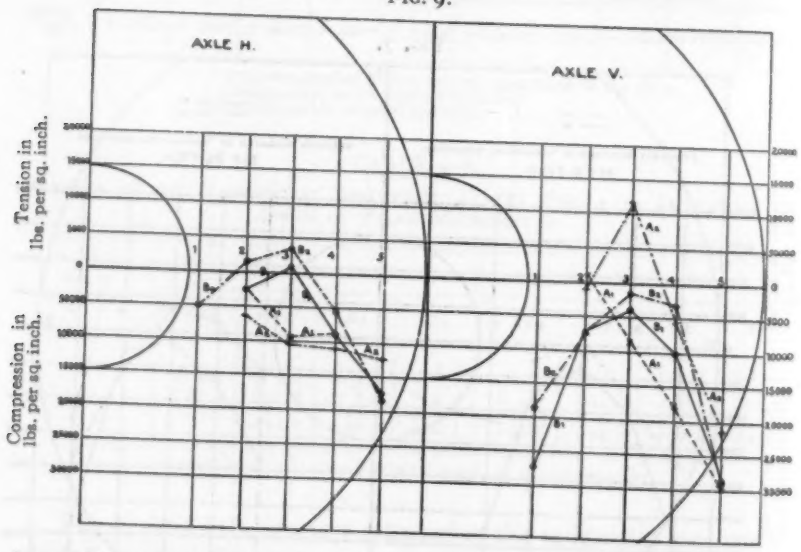
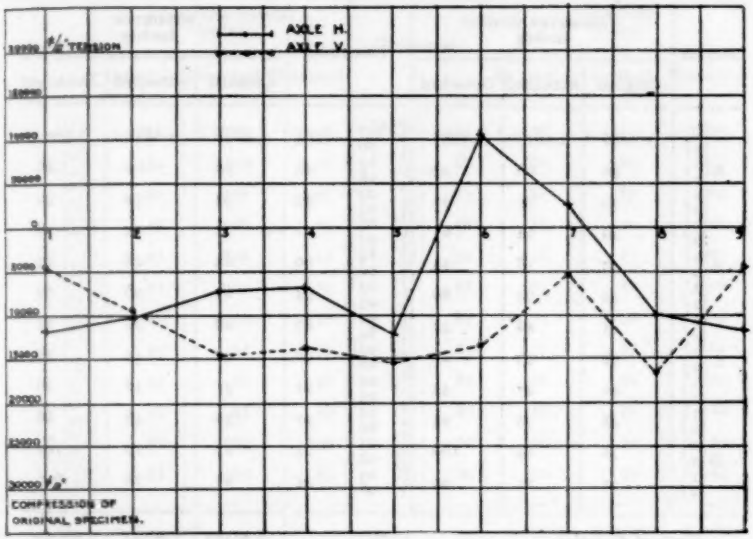


FIG. 9.



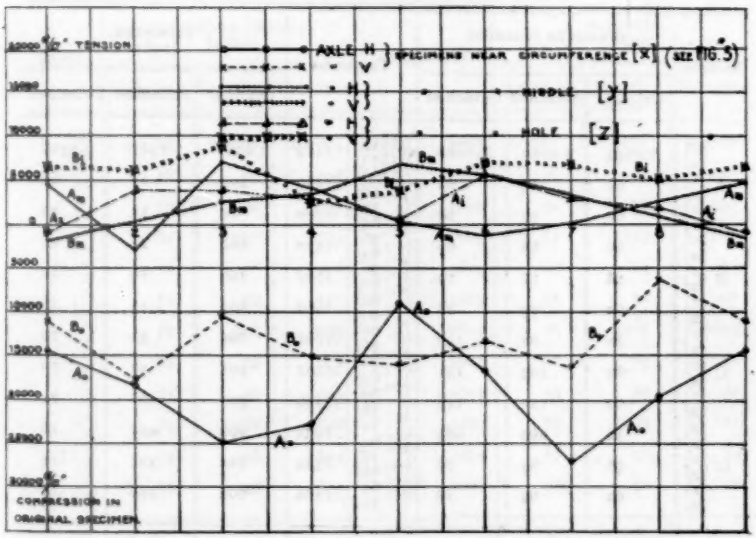
imposed, although the specimens are located on a centre line at an angle of 90 with each other. We can see from this plot that the stresses, and especially the difference in the stresses on

FIG. 10.



Internal stresses in two 10" axles as found in radial specimens.
Average results from similar positions.

FIG. 11.



Internal stresses in two 10" axles as found in longitudinal specimens (see Fig. 5).

AXLE: H SET 1 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.7036	3.7053	3.7083	.1597	.1594	3.8630	3.8647	3.8677
A 2				90				
A 1	40	66	90	95	96	36	62	86
A 2				98				
B 1	39	75	97	93	95	34	70	92
B 2				97				
B 1	30	64	67	88	91	21	55	58
B 2				93				
B 1	32	58	55	89	90	22	48	45
B 2				92				
C 1	33	62	66	93	94	27	56	60
C 2				95				
C 1	41	48	34	90	87	28	35	21
C 2				84				
C 1	50	53	40	96	92	43	45	32
C 2				88				
D 1	40	47	35	92	91	31	38	26
D 2				90				
D 1	48	55	95	93	91	39	46	86
D 2				89				
D 1	30	84	106	93	95	25	79	791
D 2				97				
1	32	81	04	95	95	27	76	699
2				96				
Mean of diameter:						3.86302	3.86548	3.86653
Mean of total strain:							.00246	.00351
Mean of total stress:						#/□	19100	27250

AXLE: H SET 1 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	8.0054	8.0080	8.0088	.1553	.1563	7.8491	7.8517	7.8525
A 2				.1572				
A 1	60	85	82	.1562	.1560	500	25	22
A 2				58				
B 1	60	75	86	55	.1560	500	15	26
B 2				65				
B 1	66	80	60	56	.1560	506	20	00
B 2				64				
B 1	58	72	72	58	.1562	496	10	10
B 2				66				
C 1	62	75	78	60	.1560	502	15	18
C 2				60				
C 1	70	94	140	66	.1561	509	33	79
C 2				56				
C 1	62	103	131	58	.1561	501	42	70
C 2				63				
C 1	62	120	143	60	.1559	503	61	84
C 2				58				
D 1	58	059	084	72	.1568	490	491	16
D 2				64				
D 1	66	63	76	58	.1562	504	501	14
D 2				66				
1	60	69	78	65	.1560	500	509	18
2				55				
Mean of diameter:						7.85002	7.85199	7.85318
Mean of total strain:							.00197	.00316
Mean of total stress:						#/□	7500	12100

AXLE: H SET 1 RING 2

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	5.0888	5.0889	5.0908	.1576	.1582	5.2470	5.2471	5.2490
A 2	84	902	02	88				
A 1	92	906	06	84	87	71	89	89
A 2				90				
B 1	85	906	20	82	83	75	89	89
B 2	97	898	12	83				
B 1	91	900	14	92	86	71	92	506
B 2				80				
C 1	95	12	22	80	79	76	77	491
C 2	90	03	30	78				
C 1	93	07	28	80	82	73	82	96
C 2				84				
D 1	76	03	02	76	80	75	92	502
D 2	90	893	896	84				
D 1	88	97	93	80	84	74	87	14
D 2				88				
				82	83	76	90	11
				83				
				90	87	63	90	489
				84				
				76	79	69	72	75
				82				
				83	82	70	79	75
				81				
Mean of diameter:						5.24719	5.24842	5.24939
Mean of total strain:							.00123	.00220
Mean of total stress:						#/□	7030	12580

AXLE: H SET 1 RING 4

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.3568	9.3608	9.3704	.1598	.1601	9.1967	9.2007	9.2103
A 2				.1604				
A 1	76	34	708	.1600	.1600	76	34	108
A 2				.1599				
B 1	72	30	695	.1605	.1602	70	28	093
B 2				.1600				
B 1	64	558	574	.1598	.1603	61	.1955	.1971
B 2				.1608				
C 1	70	68	568	.1604	.1604	66	64	64
C 2				.1604				
C 1	72	66	570	.1602	.1604	68	62	66
C 2				.1606				
D 1	58	608	636	.1596	.1602	56	.2006	.2034
D 2				.1608				
D 1	68	04	642	.1604	.1601	67	03	41
D 2				.1598				
	74	22	640	.1600	.1601	73	21	39
				.1602				
	64	588	636	.1592	.1595	69	.1993	41
				.1598				
	72	96	624	.1604	.1605	67	91	19
				.1606				
	68	90	630	.1598	.1600	68	90	30
				.1603				
Mean of diameter:						9.19673	9.19928	9.20341
Mean of total strain:							.00255	.00668
Mean of total stress:						#/□	8320	21800

AXLE: H SET 2 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.7043	3.7066	3.7130	.1541	.1541	3.8584	3.8607	3.8661
A 2				42				
B 1	38	55	65	.1545	.1539	77	594	04
B 2				33				
C 1	42	56	76	.1541	.1541	83	597	17
C 2				40				
D 1	53	69	70	.1542	.1542	95	611	12
D 2				42				
Mean of diameter:						3.85847	3.86023	3.86235
Mean of total strain:							.00176	.00388
Mean of total stress:						#/□	13700	30200

AXLE: H SET 2 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	8.0010	8.0016	8.0035	.1590	.1591	7.8419	7.8425	7.8444
A 2				92				
B 1	7.9990	03	12	88	.1592	398	11	20
B 2				96				
C 1	93	00	06	93	.1591	402	09	15
C 2				90				
D 1	8.0005	17	36	92	.1591	414	26	45
D 2				90				
Mean of diameter:						7.84082	7.84177	7.84310
Mean of total strain:							.00095	.00228
Mean of total stress:						#/□	3630	8730

AXLE: H SET 3 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.6996	3.7020	3.7035	.1519	.1523	3.8519	3.8543	3.8558
A 2				26				
B 1	.7000	12	30	25	.1526	26	38	56
B 2				28				
C 1	08	16	29	30	.1526	34	42	55
C 2				22				
D 1	05	03	43	26	.1526	31	29	69
D 2				27				
Mean of diameter						3.85275	3.85380	3.85595
Mean of total strain:							.00105	.00320
Mean of total stress:						#/□	8180	24900

AXLE: H SET 2 RING 2

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	5.0198	5.0214	5.0270	1480	.1483	5.1681	5.1697	5.1753
A 2				85				
B 1	80	12	05	83	.1485	65	97	690
B 2				87				
C 1	76	15	64	80	.1482	58	97	746
C 2				83				
D 1	200	40	72	82	.1482	82	722	754
D 2				81				
Mean of diameter:						5.16715	5.17033	5.17358
Mean of total strain:							.00318	.00643
Mean of total stress:						#/□	18450	37300

AXLE: H SET 2 RING 4

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.4021	9.4083	9.4056	1530	.1540	9.2481	9.2543	9.2516
A 2				50				
B 1	05	43	102	30	.1531	74	12	71
B 2				32				
C 1	10	32	095	28	.1527	83	05	68
C 2				26				
D 1	20	58	053	35	.1532	88	26	21
D 2				30				
Mean of diameter:						9.24815	9.25215	9.25440
Mean of total strain:							.00400	.00625
Mean of total stress:						#/□	12980	20280

AXLE: H SET 3 RING 2

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	5.0105	5.0109	5.0136	1540	.1544	5.1649	5.1653	5.1680
A 2				47				
B 1	06	21	28	49	.1548	54	69	76
B 2				47				
C 1	00	12	19	51	.1550	50	62	69
C 2				49				
D 1	03	08	43	48	.1547	50	55	90
D 2				46				
Mean of diameter:						5.16508	5.16598	5.16788
Mean of total strain:							.00090	.00280
Mean of total stress:						#/□	5230	16260

AXLE: H SET 3 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	7.9901	7.9912	7.9928	1532	.1533	7.8368	7.8379	7.8395
A 2				34				
B 1	02	906	47	32	.1531	71	75	416
B 2				30				
C 1	00	899	38	31	.1535	65	64	403
C 2				39				
D 1	04	926	32	33	.1537	67	89	395
D 2				41				
Mean of diameter:						7.83678	7.83768	7.84023
Mean of total strain:							.00090	.00345
Mean of total stress:						#/□	3450	13200

AXLE: V SET 1 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.7060	3.7071	3.7100	.1554	.1552	3.8612	3.8623	3.8652
A 2				49				
B 1	65	84	133	58	.1559	24	43	92
B 2				61				
C 1	60	96	121	53	.1557	17	53	78
C 2				60				
D 1	55	60	095	49	.1555	10	15	50
D 2				60				
Mean of diameter:						3.86158	3.86335	3.86680
Mean of total strain:							.00177	.00522
Mean of total stress:						#/□	13750	40550

AXLE: V SET 1 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	7.9945	7.9940	7.9932	1560	.1572	7.8373	7.8368	7.8360
A 2				85				
B 1	50	51	90	75	.1573	77	78	417
B 2				70				
C 1	47	65	70	76	.1576	71	89	394
C 2				76				
D 1	50	52	32	80	.1578	72	74	354
D 2				76				
Mean of diameter:						7.83732	7.83772	7.83813
Mean of total strain:							.00040	.00081
Mean of total stress:						#/□	1530	3100

AXLE: H SET 3 RING 4

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.3695	9.3710	9.3737	.1602	.1601	9.2094	9.2109	9.2136
A 2				.1601				
B 1	97	35	770	.1597	.1601	096	34	169
B 2				.1604				
C 1	95	52	795	.1590	.1595	100	57	200
C 2				.1600				
D 1	97	13	702	.1591	.1595	102	18	107
D 2				.1599				
Mean of diameter:						9.20980	9.21295	9.21530
Mean of total strain:							.00315	.00550
Mean of total stress:						#/□	10250	17900

AXLE: V SET 1 RING 2

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	5.0180	5.0212	5.0215	.1430	.1429	5.1609	5.1641	5.1644
A 2				.1428				
B 1	82	80	191	.1428	.1426	08	06	17
B 2				.1424				
C 1	74	96	226	.1424	.1430	04	26	56
C 2				.1436				
D 1	80	85	185	.1422	.1427	07	12	12
D 2				.1432				
Mean of diameter:						5.16070	5.16212	5.16323
Mean of total strain:							.00142	.00253
Mean of total stress:						#/□	8260	14700

AXLE: V SET 1 RING 4

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.3767	9.3785	9.3803	.1544	.1542	9.2225	9.2243	9.2261
A 2				.1540				
B 1	67	770	780	.1542	.1542	25	28	238
B 2				.1542				
C 1	67	765	744	.1543	.1541	26	24	203
C 2				.1538				
D 1	67	802	845	.1545	.1544	23	58	301
D 2				.1543				
Mean of diameter:						9.22248	9.22383	9.22508
Mean of total strain:							.00135	.00260
Mean of total stress:						#/□	4390	8460

AXLE: V SET 2 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.4669	3.4716	3.4709	1461	.1467	3.6136	3.6183	3.6176
A 2				73				
A 1	73	06	09	85	.1480	53	86	89
A 2				75				
1	59	3.4681	3.4689	99	91	50	72	80
2				82				
B 1	99	3.4745	3.4737	59	65	64	3.6210	3.6202
B 2				71				
B 1	93	29	36	75	81	74	10	17
B 2				88				
1	82	03	18	92	91	73	3.6194	09
2				90				
C 1	81	23	10	61	66	47	89	3.6176
C 2				71				
C 1	86	15	10	78	88	74	3.6203	98
C 2				97				
1	77	3.4693	3.4695	95	99	76	3.6192	94
2				1504				
D 1	77	3.4735	3.4730	1461	59	36	94	89
D 2				57				
D 1	83	21	23	65	71	54	92	94
D 2				76				
1	63	3.4681	06	91	88	51	75	94
2				85				
Mean of diameter:						3.61573	3.61927	3.61932
Mean of total strain:							.00344	.00359
Mean of total stress:						#/□	28500	29800

AXLE: V SET 2 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	7.9922	7.9938	7.9987	.1518	.1520	7.8402	7.8418	7.8467
A 2				22				
A 1	37	47	90	40	33	04	14	57
A 2				26				
1	57	62	90	43	35	22	27	55
2				27				
C 1	36	53	98	16	23	7.8413	30	75
C 2				30				
C 1	63	63	8.0001	24	34	7.8430	30	68
C 2				43				
1	73	74	01	35	39	33	34	61
2				44				
1	25	26	19	16	17	09	10	7.8503
2				17				
C 1	51	52	21	25	26	25	26	7.8495
C 2				27				
1	83	65	27	33	34	49	31	93
2				35				
1	23	55	7.9957	18	23	00	32	34
2				28				
D 1	45	74	62	27	33	12	41	29
D 2				39				
1	66	83	65	38	39	27	44	26
2				40				
Mean diameter:						7.84188	7.84281	7.84638
Mean of total strain:							.00093	.00450
Mean of total stress:						#/□	3560	17220

AXLE: V SET 2 RING 2

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	4.8565	4.8581	4.8579	.1365	.1368	4.9933	4.9949	4.9947
A 2	69	73	62	70		61	66	55
A 1	53	53	48	81	.1392	60	60	55
A 2				.1406				
B 1	72	4.8608	4.8634	.1399	.1407	43	79	4.5005
B 2	67	4.8586	4.8599	.1415		53	72	9985
C 1	72	82	92	.1373	.1371	73	83	93
C 2	73	79	59	69		42	48	28
C 1	63	67	26	98	.1386	63	67	26
C 2	44	60	18	73		65	81	39
D 1	77	4.8607	4.8644	.1422	.1401	41	71	5.0008
D 2	62	4.8582	07	.1381		57	77	5.0002
D 1	55	63	00	63	.1369	62	70	5.0007
D 2				75				
				98	.1400			
				.1402				
				20	.1421			
				21				
				.1369	.1364			
				59				
				.1401	.1395			
				.1389				
				.1421	.1407			
				.1393				
Mean of diameter:						4.99545	4.99685	4.99708
Mean of total strain:							.00140	.00163
Mean of total stress:						#/□	8400	9810

AXLE: V SET 2 RING 4

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.3557	9.3591	9.3639	.1500	.1496	9.2061	9.2095	9.2143
A 2	57	70	28	.1492		62	75	33
A 1	57	52	15	.1500	96	63	58	21
A 2				.1491				
B 1	87	9.3624	73	.1500	93	89	9.2126	75
B 2	87	05	40	.1487		95	13	48
C 1	87	9.3587	29	.1499	99	97	9.2097	39
C 2	76	82	9.3788	.1498		95	9.2101	9.2308
C 1	76	80	86	.1495	91	97	01	07
C 2	76	73	70	.1488		96	9.2093	9.2290
D 1	59	89	9.3520	90	90	73	9.2103	9.2034
D 2	59	79	04	90		73	9.2093	18
D 1	59	60	94	81	81	73	74	08
				81				
				78	80			
				81				
				78	79			
				81				
				87	86			
				85				
				87	86			
				85				
				88	87			
				85				
Mean of diameter:						9.20829	9.20958	9.21537
Mean of total strain:							.00129	.00708
Mean of total stress:						#/□	4080	23050

AXLE: V SET 3 RING 1

Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	3.7070	3.7072	3.7080	.1492	.1491	3.8561	3.8563	3.8571
A 2				.1490				
B 1	67	78	094	.1498	.1500	67	78	594
B 2				.1503				
C 1	65	83	094	.1506	.1504	69	87	598
C 2				.1502				
D 1	64	77	120	.1496	.1494	58	71	614
D 2				.1492				
Mean of diameter:						3.85638	3.85748	3.85943
Mean of total strain:							.00110	.00305
Mean of total stress:						#/□	8560	23700

AXLE: V SET 3 RING 3

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	8.0050	8.0067	8.0103	.1527	.1529	7.8521	7.8538	7.8574
A 2				31				
B 1	50	63	66	21	.1517	33	46	49
B 2				13				
C 1	40	53	71	20	.1523	17	29	48
C 2				26				
D 1	38	39	37	22	.1524	14	15	13
D 2				26				
Mean of diameter:						7.85212	7.85320	7.85460
Mean of total strain:							.00108	.00248
Mean of total stress:						#/□	4120	9480

AXLE: V SET 3 RING 2

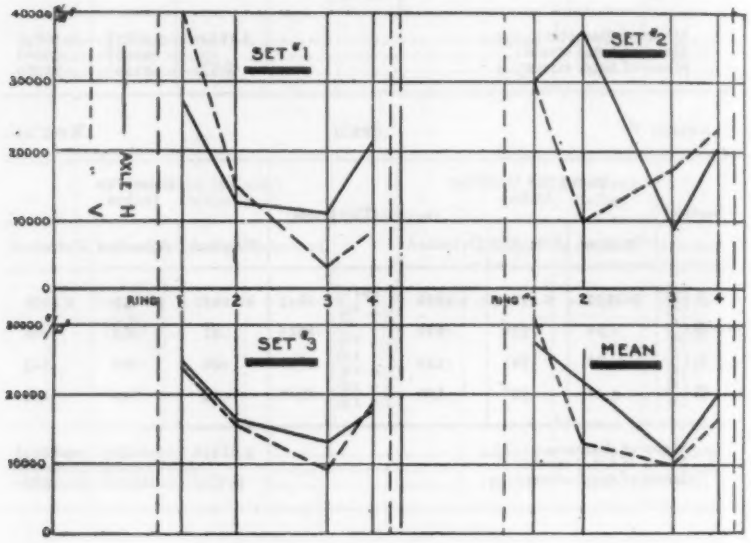
Section	DIAMETER (inside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	5.0195	5.0196	5.0189	1465	.1462	5.1657	5.1658	5.1651
A 2				58				
B 1	92	198	244	72	.1470	62	68	.1714
B 2				69				
C 1	90	196	210	72	.1469	59	65	679
C 2				66				
D 1	91	213	232	58	.1459	50	72	691
D 2				60				
Mean of diameter:						5.16570	5.16658	5.16838
Mean of total strain:							.00088	.00268
Mean of total stress:						#/□	5110	15560

AXLE: V SET 3 RING 4

Section	DIAMETER (outside) Inches			Thickness		DIAMETER Inches		
	Original	Attached	Detached			Original	Attached	Detached
A 1	9.3757	9.3772	9.3806	1611	.1615	9.2142	9.2157	9.2191
A 2				19				
B 1	50	776	821	10	.1613	37	63	208
B 2				16				
C 1	52	801	755	13	.1612	40	89	143
C 2				11				
D 1	41	757	850	22	.1617	24	40	233
D 2				12				
Mean of diameter:						9.21358	9.21623	9.21938
Mean of total strain:							.00265	.00580
Mean of total stress:						#/□	8630	18880

different points on the same longitudinal plane (parallel to the axis), are considerably greater in axle "V" than in axle "H." It is also to be noted with the vertically quenched axle that the stresses are a maximum near the outside surface and near the surface of the centre hole, and a minimum half way between these two points, while with the horizontally quenched axle the stresses do not tend to rise to so high a maximum near the centre hole.

FIG. 12.



Mean stresses as found by method (*a*).

One point, A 2-3, departs from the apparent rule, and this may have been due to a hard spot, some of which were noticed during machining.

The curves shown on Figs. 6, 7, and 8 have been replotted in Fig. 9. Here the values of the tangential specimens of each axle are plotted separately; furthermore the values of the specimens located in juxtaposition are shown revolved through 180. From this plot one can see even more clearly the greater stresses in axle "V" than in axle "H."

Fig. 10 is the plot of the stresses released in the radial specimens, and in this case it will be noted that one side of the section of axle "H" is shown in tension, the balance in compression;

whereas the stresses in axle "V" throughout the entire section are compressive.

Fig. 11 is the plot of the stresses released in the longitudinal specimens, and it will be noted that this is the only curve which shows the stresses in axle "H" to be greater than those of axle "V." The greater uniformity of stresses in axle "V" will be noted as well as the great difference between the stresses on the outside of both axles and the stresses in the middle and inside, the former being in compression while the middle and inside are slightly in tension.

Fig. 12 shows the stresses plotted from the three sets of rings and the mean of these curves, and it can be seen that they do not give as complete or satisfactory information as the curves obtained by method (*b*).

CONCLUSIONS.

1. Method (*a*) does not furnish desired results, as only relative values of the mean stresses in concentric rings can be obtained. Differences in stresses in the different parts of the rings, as was indicated by variations in the ring diameters, could not be obtained and plotted.

2. The stresses and their distribution can be found by method (*b*), as far as can be judged from the few tests made.

3. It is very possible and probable that the stresses are distributed more or less unsymmetrically throughout the length of the axle with respect to a plane perpendicular to the axis in the vertically quenched axle "V," and with respect to the axis itself in the case of the horizontally quenched axle "H." In order to investigate this it would be necessary to take specimens from both ends and the middle of the axle.

4. Fig. 9 shows that the stresses on different points of concentric rings differ considerably. It also shows that the influence of quenching in axle "V" (vertically quenched) is much greater than in axle "H" (horizontally quenched).

5. Fig. 9 also shows that the stress curves of the tangential specimens and longitudinal specimens in juxtaposition are similar.

6. All conclusions derived from the experiments must be used conservatively, on account of the small number of tests, and due to the fact that only one specimen of each kind and location was

measured. Nevertheless, it would appear that the heat treatment has had a much greater effect upon the vertically quenched than upon the horizontally quenched axle, in that the stresses are greater, and it would also appear that the stresses are somewhat more evenly distributed in the vertically quenched than in the horizontally quenched axle.

7. The results show that the problem of finding the internal strains in forgings can be satisfactorily solved, for practical purposes, by a method of microscopic measurement and valuable results obtained if a sufficient number of specimens be used.

Production of High Vacua by Means of Finely-divided Copper. T. R. MERTON. (*Chem. Soc. Journ.*, cv, 645.)—Finely-divided copper, which may be obtained by reducing a solution of a copper salt and is sold commercially as "precipitated copper," absorbs gases with great readiness, the vapor pressure of the gases thus absorbed being so small that under suitable conditions it may be used for the production of high vacua. A bulb containing a few grammes of the copper is sealed to the vessel to be exhausted, the vessel being then partially exhausted by means of an air-pump and the copper heated to about 250° C. When the air-pump is disconnected and the copper allowed to cool, the residual gases are rapidly absorbed. This absorption is not due to chemical combination, since the gases are liberated when the copper is heated. The carbon bands disappear first, then nitrogen, finally hydrogen, but helium does not appear to be absorbed appreciably. Diminution of the absorptive power of the copper follows (1) the use of an excessively high temperature, (2) repeated use, or (3) prolonged exposure to the mercury vapor from a mercury pump. Great care is necessary when the copper is being used for the first time, as the occluded gases may sometimes be evolved with such violence that the copper is blown through into the pump; consequently not more than one-third of the bulb should be filled with copper; and a short length of the tube connecting the bulb and the pump should be tightly packed with glass wool.

The Aluminum Cell Lightning Arrester. E. E. F. CREIGHTON. (*Amer. Inst. Elect. Eng. Proc.*, xxxiii, 795.)—A review of the present position of the aluminum cell as a form of protection against lightning. When used on direct current it is said to give the highest possible form of protection. On alternate current the following points are considered, *viz.*, dielectric spark log, dissolution of film, charging resistance, oscillations, damping, degrees of surge due to natural operations, and insulations which withstand these surges. On the whole, it is considered to be a device which is likely to do all the work which is thrown upon it.

THE EXUDATION OF ICE FROM STEMS OF PLANTS.*

BY

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I. INTRODUCTION.

NOCTURNAL radiation is generally a passing of radiant energy from terrestrial substances into space. On a clear night the rate at which radiation passes outward from the earth's surface is very great, amounting to almost one-tenth of the solar constant. Of course, not all substances lose heat at this rate. This loss of heat by radiation produces peculiar formations of ice, some of which will now be mentioned.

Ground Ice.—The most familiar freak of ice formation occurs on bare, clayey soils which contain a certain (minimum) amount of moisture. If the moisture content of the soil falls below this minimum value (which no doubt varies for different soils), then evaporation occurs as rapidly as the moisture is brought to the surface (by capillary action) and no ice is formed. According to the writer's observations, the ice is formed in contact with a nucleus which may be a grain of sand, a small pebble, etc. The earthy material has a higher emissivity than the water, it cools the more rapidly and the water is frozen to the under side of the nucleus. As heat is lost, more ice is formed, and, as it accumulates, rises in columns, as is to be observed everywhere on cold mornings. The water is supplied by capillary movement in the soil, from the surface of which the ground ice may be readily lifted, since in freezing weather the ice is not frozen into the soil.[1] The general experience is to find the ground ice supporting a nucleus (say a grain of sand, or even large stones—3 x 1½ x 1 inches in size). The nuclei may be thinly distributed. The writer has observed several large areas, 3 x 1½ feet, which did not contain nuclei, from which it appears that this type of ice formation can occur without having a nucleus (gravel, etc.) to start the refrigeration.

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* Communicated by the Author.

[1] Abbe, *Amer. Meteorological Jour.*, 9, p. 523, 1893.

Anchor Ice.—Barnes [2] has made a prolonged study of the formation of anchor ice at the bottom of the St. Lawrence River. This kind of ice consists of fine spicules which adhere to the bottom of the river. It is a friable mass which may vary from six to eight feet in thickness. According to Barnes, this ice is formed as a result of the greater emissivity and hence the greater cooling of the material composing the river bottom.

Hoar-frost is another example of ice formation as the result of cooling by radiation. Here, however, the accepted explanation is that the ice spicules are formed by accretion, as the result of the deposition of moisture from the surrounding air.

The foregoing are familiar and interesting illustrations of ice formations on substances as the result primarily of the loss of heat by radiation. We have now to consider a rarer phenomenon, which is the subject of the present paper.

Ice Formations on Plants.—According to the writer's observations, the amount of ice formed upon a plant stem is a function of (1) the rate at which water can rise by capillary action in the sap tubes within the stem, (2) the ease with which the moisture can pass out to the surface, (3) the rate of evaporation from the surface (convection, wind-velocity), and (4) the emissivity of the surface of the stem. Instead of the title "Exudation of Ice," a more pretentious title would have been "The Capillary Movement of Water: An Experimental Demonstration by Means of the Formation of Ice Fringes on Plants." This might appear more scientific and one could discuss the capillary movement of water as a function of the temperature of the stem; the size of bore and number of (sap) tubes; the thickness and permeability of the walls of these tubes, etc. However, the present communication makes no pretence at such completeness of the investigation. In fact, the subject of ice formation forced itself upon the writer at a time when other duties were pressing, and hence it could not be given the attention it deserved. As a result, the experimental tests, to be described presently, were usually carried out only to the extent of refuting the various notions held by various persons as to the cause of this ice formation. All sorts of explanations were presented. This is the main reason for

[2] "Ice Formation with Special Reference to Anchor Ice and Frazil," H. T. Barnes, *Monthly Weather Review*, May, 1907, p. 225.

giving *in extenso* these simple tests, which show that the formation of fringes of ice on plant stems is not the result of accretion, hydrostatic pressure, rifts in the stem, moisture in the bark, the presence of sap, etc., but that it is the result primarily of the capillary movement of water in the numerous sap tubes which are to be found in those plant stems upon which the ice formations are the most conspicuous.

II. HISTORICAL DATA.

One of the earliest descriptions of the exudation of ice fringes from plants was published by Herschel [3] about eighty years ago. His observations relate to the icy fringes which were formed around thistle stalks and stumps of heliotropes, many specimens of which were still green. Stephen Elliott [4] had previously described a remarkable protrusion of fringes of ice from the stems of fleabane (*Conyza bifrons*).

The fullest account, with an attempted explanation of this phenomenon, was given by John Le Conte [5] about 63 years ago. His observations are on two species of fleabane, *Pluchea bifrons* and *Pluchea camphorata,* which he found growing in wet soils, around ponds and along roadside ditches in the lowlands of South Carolina and Georgia. In these plants the root is perennial, but the stem is annual and herbaceous.

Le Conte's descriptions differ materially from my own. His observations appeared to establish the following facts in relation to the phenomenon:

1. "The depositions of ice are entirely confined to the immediate neighborhood of the roots of the plants, the upper parts of the tall, unbroken stalks being quite free from them. They frequently commence two or three inches from the ground, and extend from three to four inches along the axis of the stem. The stalks are dead, and quite dry to within about six inches of the earth, below which they are generally green and succulent. The plant has a large and porous pith, which is always saturated with moisture as high as six or seven inches from the base of the

[3] Sir John Herschel, *Phil. Mag.* (3), 2, p. 110, 1833.

[4] Stephen Elliott, "Sketch of the Botany of South Carolina and Georgia," published in 1824, vol. 2, p. 322. Quoted by Le Conte.

[5] John Le Conte, *Proc. Amer. Assoc. Adv. Sci.*, vol. 3, p. 20, 1850.

stem." From this it would appear that the ice was formed on the green stems, as was true of many of the specimens of heliotrope described by Herschel.

2. "The ice emanates in a kind of riband, or frill-shaped, wavy, friable, semipellucid excrescence, the structure of which (quoting Herschel) is 'fibrous like that of the fibrous variety of gypsum, presenting a glassy, silky, wavy surface; the direction of the fibres being at right angles to the stem or horizontal.'" Le Conte found that the number of ribands varied from one to five, which issued from the stems in vertical or longitudinal lines, often unsymmetrically displaced around the axis. He frequently observed the icy excrescences to exceed five inches in length; often curled back so that the remote extremity of the frill came close to the line of attachment to the stalk.

From this it may be noticed that the amount of ice formed is very considerable. Evidently the moisture must come from within the plant. The amount of water congealed during a single night is vastly too great to come from the aqueous vapor in the atmosphere, hence the phenomenon cannot be a modification of hoar-frost. In fact, in the illustrations to be cited presently, which were observed by the writer, the excrescences of ice on one particular species of plant were formed every night which was sufficiently cool for ice formation, although there was little or no formation of hoar-frost anywhere in the vicinity.

3. Although the ice sheets appeared to protrude from the interior of the stem, both Herschel and Le Conte found that usually the stems were solid and that the ice terminated at the surface. "The point of attachment of the ice was always the wood, beneath the outer bark or epidermis, which the frozen sheets had in every instance stripped off and forced out to a distance." When the frost was severe, Le Conte found that the ice riband was continuous with the frozen pith, through a longitudinal rift in the woody stem.

4. Le Conte found that "the phenomenon took place in the same plant during several consecutive nights; and, when the wood was not rifted, frequently from the same portion of the stalk. When the wood was split, however, the deposition of ice occurred lower down the stem, at a part which was unaffected by the frost of the previous night. The stalks thus become completely rifted by a succession of severe nights, from the height

of six or seven inches down to the ground. This is unquestionably one of the reasons why these exudations of ice are seldom observed after the middle of the winter, for the stalks are usually destroyed before this period."

Le Conte considered the ice formation on plants to be a physical phenomenon, having no connection with the vitality of the stem. His explanation of the ice formation was that the moisture from the pith passes out along the wedge-shaped medullary rays which are to be found in abundance in this plant, and is frozen on the outside of the stem. He considered that the wedge-shaped medullary rays exerted a "projectile force" which brings the moisture to the surface. The exudation of ice columns from the earth he referred to the same cause, viz., a rapid and forcible expansion along capillary tubes.

To the writer it does not appear necessary to postulate a complex "projectile force" to explain the ice fringes on plants. In fact, the plants upon which ice is formed in the greatest abundance have a preponderance of sap tubes, only an insignificant part of the stem being occupied by medullary rays.

Ward[6] has given a rather popular description of the occurrence of ice fringes. He describes the fringes as projecting out horizontally, "not straight and stiff, but gently and gracefully curving or coiling into a beautiful, conch-like roll at the distal end." His observations were probably of short duration, otherwise he would have found but few instances in which the "fringes are attached at regular intervals around the stem, like paddles of a turbine wheel." He found that the bark was split into strips at the zone occupied by the ice sheets. He concluded that the ice had passed through these rifts in the bark. He thought that the water might have been pressed or drawn up through the cambium layer. He wisely dismisses the explanation because it "explained too much, since no reason can be assigned why the phenomenon should not be universal and not confined to one species."[7] In the present paper microphotographs of the cross-sections of various plants will assign this reason, viz., the difference in the porosity of the stems.

[6] Ward, "Frost Freaks of the Dittany," *Botanical Gazette*, 18, p. 183, 1893.

[7] Ward quotes Gray's Manual, 1848, in which *Helianthemum Canadense* is described as behaving in a similar way.

III. RECENT DATA.

During the past fall and winter (which may be called an "open" one, in that there was no snow until after December 1, 1913) the writer has been walking daily through Rock Creek Park, on his way to and from the Bureau of Standards. The route is along the "Beach Driveway," which winds along the east bank of the creek. This driveway is bordered by a steep hillside, from ten to fifty feet in height, which is thinly covered with second-growth trees, the majority of which are oaks and beeches. There is a thin undergrowth of grasses and of various herbaceous plants with annual stems and perennial roots.

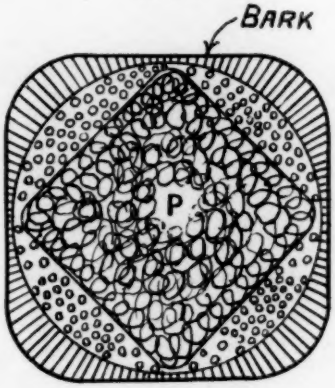
From this it may be seen that the habitat of the plant about to be described is different from the one mentioned by Le Conte, which thrives on wet soils. The present observations are on *Cunila mariana* or Dittany, the stem of which is an herbaceous annual with perennial roots. This plant seems to thrive on dry ground even on bare hillsides, exposed to the blazing sun, where there is nothing but gravel and a few "asters." Other samples were found under trees where either the shade or the gravelly character of the soil prevented a luxuriant growth of other plants. The finest samples were found on a hillside which contained plenty of moisture, which was free from trees, but contained shrubbery.

The first observations were made on a frosty morning in November, 1913. The first example, because of its white, ribbony character, was passed by, thinking it was something thrown from a passing carriage. The conspicuous white fibrous loops and ribbons drew my attention, and it was at once observed that they occurred upon only one species of herbaceous plant. A sample of the plant was sent to Prof. Cleveland Abbe, of the United States Weather Bureau, who pronounced this a rare and an interesting observation, which should be followed up by a more thorough study of the ice formations. While the problem itself seemed a very interesting one in radiation and in the capillary movement of water, it nevertheless seemed an intrusion upon a very busy program of radiation work, so that at first but little attention was given to it, other than scattered observations in passing to and from the Bureau. As time passed, many diverse opinions were received as to the cause of the ice formation. This

called forth additional tests, so that the experimental data now at hand are rather voluminous. In view of the fact that memory is treacherous, notes were taken in the field at the time of observation.

Owing to the pressure of other problems requiring close attention, the tendency at the very first was to dismiss the subject by accepting Le Conte's explanation that the moisture comes from the pith. This explanation was at once disproved, however, by the observations on the splinters of the *Cunila* stem, which formed ice always on the outside of the stem, but never on the pith. This, of course, should be expected, for pith is composed

FIG. 1.



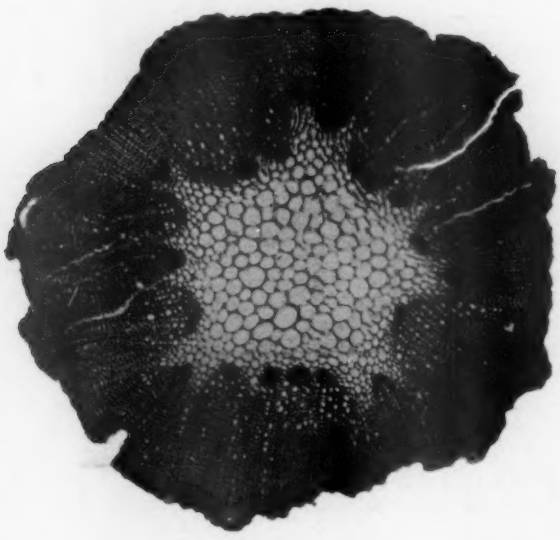
of small hexahedral cells along which water cannot pass by capillary attraction, and it would be very unlikely that it would be transferred by soaking through the cell walls.

Description of the Plant.—The stem of *Cunila mariana* is somewhat angular (especially as viewed with the bark on), having a cross-section of 1.5 to 2.5 mm. The height of the stalk is from 25 to 30 cm. (about 1 foot). The plant stems are very fragile, owing to the structure of the stems, which contain but little wood fibre. The plant is also weak in structure, owing to the great amount of pith and the manner in which the pith is arranged in the stem. As shown in Fig. 1 and Plate 5, the stem is somewhat rectangular in outline, the pith having a similar shape, but the " corners " are rotated 45 degrees. At these " corners " of the pith there is but little wood between the pith and the bark,

and it is along this line that the stem often cracks. Perhaps this is the reason for the persistent belief among the few who are acquainted with the phenomenon that the ice ribbons come from these rifts in the stem. The small stem, weakened by splitting, is an easy prey to the wind.

Photographs were taken of thin sections across the stems of heliotrope, thistle, and also of an aster which was found near a *Cunila* stalk. The object in giving these microphotographs (which were very kindly prepared by Mr. E. D. Tillyer) is

PLATE I.



Aster.

to show a typical example of plants which have but few sap tubes and which form little or no ice fringes; also typical examples of plants which have numerous sap tubes and which form an abundance of ice fringes.

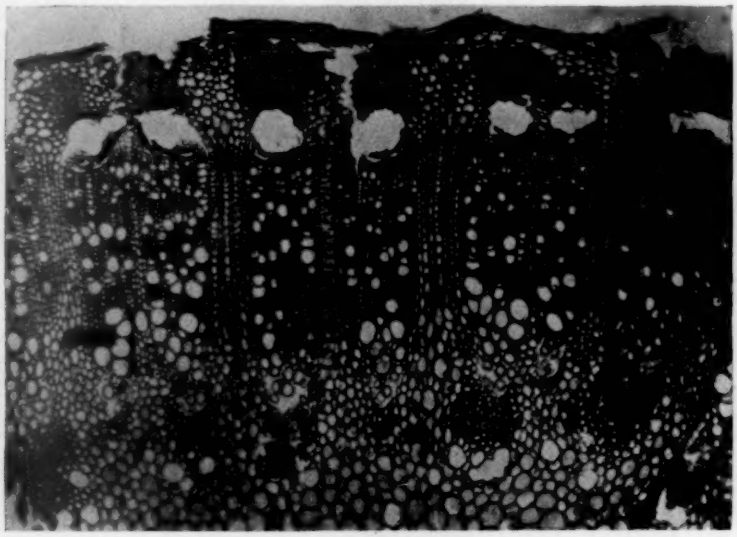
The aster is typical of plants having but few sap tubes. As shown in Plate I, the woody structure is very compact, with but few sap tubes. All these microsections are magnified fifty times, from which one can obtain some idea of the great difference in porosity of the different plants.

On only one occasion was ice observed upon the stem of

the aster. The ice was a small "tooth" formed close to the ground. From the section shown in Plate I it is evident that the structure of the wood fibre is so close that the moisture, which is drawn up within the stem by capillary attraction, can reach the surface of the stem at only a very slow rate. Hence the moisture disappears by evaporation as rapidly as it comes to the surface.

The thistle (Plate 2) and the heliotrope (Plate 3) stems have numerous large sap tubes. In the thistle stem there is a row

PLATE 2.



Thistle.

of large tubes situated near the bark. The presence of these large tubes filled with sap may explain the formation of ice fringes, as observed by Herschel.

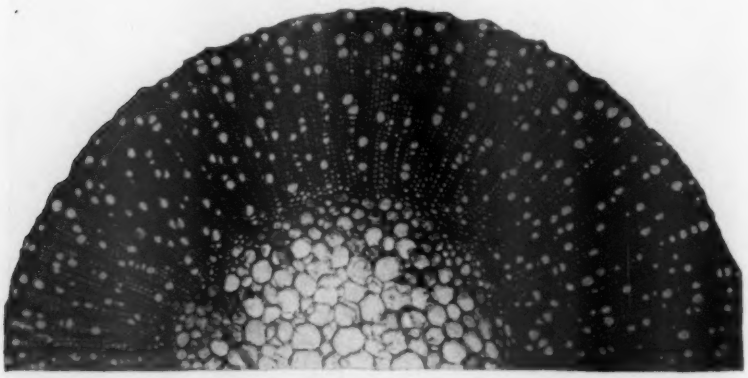
Microphotographs of thin sections of *Cunila* are shown in Plates 4 and 5. The numerous holes in the wood are the "sap tubes," which form an easy path for the moisture to rise within the stem by capillary attraction. It would be interesting to determine to what extent this capillary movement of water is affected by the temperature of the surroundings.

The explanation of the formation of ice fringes, which are

found to occur so abundantly upon the stems of the *Cunila* and which are not found upon other plants, is based upon the presence of a great number of closely adjoining sap tubes within the stem of the *Cunila*. But even the very woody portion of the base of the *Cunila* stem was found to be inactive in the formation of ice fringes.

It was found that the ice fringes rarely start from the side of the stem where the pith is closest to the bark. This eliminates, to some extent, the question whether the pith is instrumental in forming the ice fringes. In the splinters (and in the rifted stems of *Cunila*) at no time was ice found to have formed along the

PLATE 3.



Heliotrope.

line of separation of the stem. This seemed puzzling at first, for it appeared to contradict the idea that the moisture comes from the sap tubes within the stem; in which case one would expect to find the formation of ice fringes facilitated upon the surface laid bare by splitting.

The microsections of the *Cunila* stems show in a very unexpected manner why no ice fringes are formed upon the rifted surface of the stem. As already stated, the rift always occurs at the "corners" of the pith where the woody part of the stem is the thinnest. In Plates 4 and 5 it may be noticed that at these four points, where the wood is the thinnest, usually there are but few if any sap tubes. Hence one need not expect to find ice formations upon the surfaces formed by splitting.

Field and Laboratory Observations.—The field observations were made on isolated plants found scattered throughout the woods; also on three test-beds of plant-stems, without their roots, which were conveniently located along the roadway.

The first test-bed, Test No. 1, was "planted" January 7, 1914, with plant stems (10 to 15 cm. long) which had been in the laboratory since November, 1913. This test contained (1) a stem and branches with bark intact; (2) a similar stem with two coats of shellac varnish; (3) a stem having the bark thoroughly

PLATE 4.

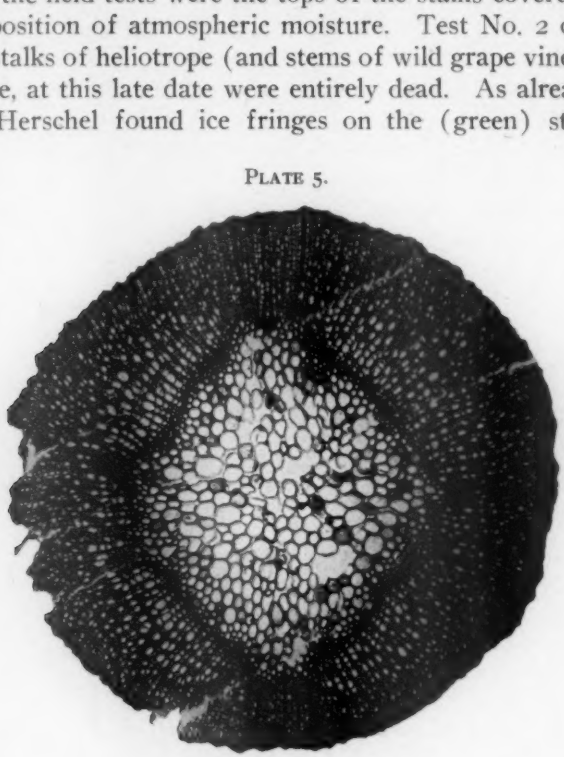
Cunila mariana.

scraped from one side, and the other side shellacked over a length of about 8 cm.; (4) a stem scraped on all sides and one-half of it shellacked; (5) a stem having half its circumference scraped, the other half having the bark intact; and (6) a stalk planted head down. The location proved to be a poor one, the ground not retaining moisture. The place was disturbed, but in spite of this some results were obtained.

Tests No 2 and No. 3 were "planted" on January 11, 1914, and consisted of about two dozen plant-tops and stems which

had been broken off by the wind. They were placed on a gravelly bank which was not desiccated by the wind and sun. Some of these stalks were covered with ground up to their branches. In none of the field tests were the tops of the stalks covered to prevent deposition of atmospheric moisture. Test No. 2 contained several stalks of heliotrope (and stems of wild grape vine) which, of course, at this late date were entirely dead. As already mentioned, Herschel found ice fringes on the (green) stumps of

PLATE 5.



Cunila mariana.

heliotrope. At no time were there ice fringes formed on the heliotrope (nor on the wild grape stems which were green), especial note of this fact having been made on January 22 and February 2, 1914.

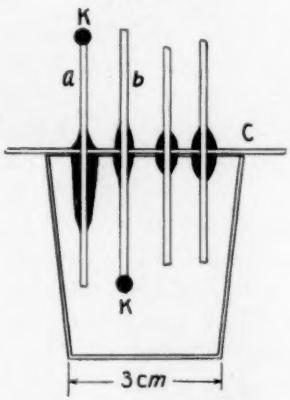
The laboratory tests (started on January 30th) were made on plant-stems placed in a receptacle containing water. In the first and second laboratory tests, "A" and "B," the samples were mounted in a small porcelain crucible, as shown in Fig. 2. The plant-stems were fastened into a piece of heavy cardboard by means of Khotinsky cement. The cardboard was then covered, on

both sides, with paraffin and sealed (with paraffin) to the top of the crucible. A small pin-hole equalized the air pressure, thus preventing any possible hydrostatic pressure. The protruding stems were covered with a glass beaker, which prevented deposition of moisture from the air.

Two additional laboratory tests were made on plant-stems placed in test "C," a test-tube, as shown in the photograph, and "D," a wide-mouthed bottle. In all these laboratory tests the stems were covered to prevent deposition of atmospheric moisture.

Experiments Showing How the Water is Conveyed.—The field observations, "Test No. 1," showed that the water is not transferred along the cambium layer or the bark. Ice was formed

FIG. 2.



on that half of the stem which was scraped, but none was formed upon the part (whether scraped or unscraped) which was covered with shellac. This observation was confirmed on different occasions, especial note of this fact having been made (Test 1, Nos. 3 and 4) on January 8th, 12th, and 27th, and February 2nd and 3rd. In No. 2 of this test the ice forced out the shellac at the juncture of two branches on February 3rd. On these dates (as well as others which would be too tedious to record in this paper) my notes show that ice fringes, large and small, were formed upon numerous plants contained in the plats described as Tests 1, 2, and 3.

The laboratory tests "A" and "B" showed that, starting with stems which had been drying for nine weeks in the labora-

tory, the moisture is transferred very rapidly after placing the stems in water. In Test "A" (see Fig. 2), four scraped samples were thoroughly covered with an impervious cement at the point of contact with the cardboard (*C*). About 2.5 cm. of the stems extended above the support. The next morning (January 30th) two samples were found thoroughly soaked They were from the upper part of the plant, hence thin-walled and less "woody." The third sample, which was taken from near the root, was inactive. The fourth showed slight moisture at the top, and by night (24 hours in all) this sample was thoroughly soaked.

The second laboratory test "B" consisted of the two most active samples of Test A thoroughly dried and covered with cement (*K*), as shown in Fig. 2, and placed in water containing a red dye. The sample, *a*, was covered at the top, *K*, so that the water would have to come out at the sides. The sides of the immersed part of this stem were covered with cement, so that the water would have to traverse the sap tubes in order to reach the top. The immersed end of sample *b* was covered with cement so that the water would have to soak in through the sides in order to traverse the stem.

The next morning, February 3, 1914, (uncolored) moisture was observed on the sides of *a*, and the top of *b* showed the red dye. Evidently the water had traversed the stems to a height of about 3 cm. by capillary movement. In the subsequent tests, "C" and "D," the stems were more than 6 cm. in length, and it was found that the water rose to a height of 5 cm. However, when uncovered and exposed to the wind the moisture did not rise higher than 1 cm. to 2 cm.

Further Tests Showing That the Water Comes from Within the Stems.—There are several observations which indicate that the water required for the formation of ice fringes comes from within the stem, and that it is not caused by accretion or sublimation, as in hoar-frost. One of the observations applicable to this question was made in connection with the laboratory tests, "C" and "D," discussed elsewhere in this paper. The morning following the formation of the ice fringes on the *Cunila* stems it was observed that considerable water had disappeared from the glass receptacles. The glass beakers covering the stems were perfectly clear, showing that no water vapor had condensed (and frozen) upon them. Evidently the ice fringes had been

formed from the water which had disappeared from the glass receptacles.

Another observation (January 6th) was on a plant (in the woods) surrounded with green moss and well covered with leaves of trees. The stem had several large ice fringes which were hidden by leaves. The leaves were covered with hoar-frost.

A very convincing field test was made by painting the stems with asphaltum in turpentine. If the ice formations were the result of condensation of moisture by rapid cooling, then the black paint should have ice formed upon it. In the afternoon of January 13th (the ice fringes having melted as usual) a number of *Cunila* plants free from bark, situated in various parts of Rock Creek Park, were given a coating of asphaltum paint. "Test No. 2," mentioned elsewhere in this paper, contained several painted stems. As shown in the photographs, the outer edge of the ice fringe is smooth, which could hardly be the case if the formation were similar to that of hoar-frost. On January 27th it was found that ice fringes on two plants in Test No. 2 had pushed out the asphaltum varnish, which was found adhering to the outer edge of the ice, 1.5 to 2 cm. from the stem of the plant.

In Test No. 4 the ice had pushed out the asphaltum and had formed a fringe in the rent in the paint. For some days subsequent to this date there was no freezing weather; but on February 3rd other stalks were found in which the asphaltum varnish was pushed out by, and was situated on the outer edge of, the ice fringe. It may be added that for some days after applying the asphaltum paint the formation of ice fringes seemed to be inhibited.

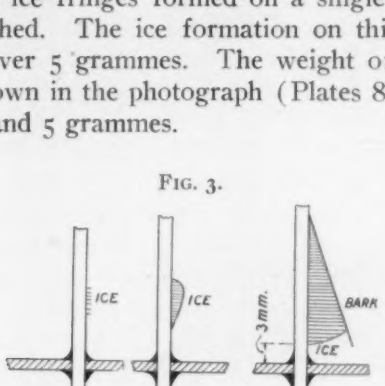
The field tests (Test 1), described elsewhere in this paper, in which one side of the stem was covered with shellac varnish, showed that the moisture was not conveyed from the ground upward along the outside of the stem.

In view of the fact that the bark is often found pushed out by the ice, these tests with asphaltum seem superfluous; but the persistence with which the hoar-frost theory was presented to account for this ice formation seemed to require a *reductio ad absurdum* test. The mere fact that hoar-frost is in fine spicules, while these fringes are smooth, should be sufficient evidence to disprove the hoar-frost theory. If sublimation by cooling had been the cause, then the black paint, with its high emissivity

("cooling power"), should have produced a great amount of hoar-frost upon the outside of the paint. The ice fringes were always formed on nights when the temperature was sufficiently low to cause freezing, whether or not there was hoar-frost in the vicinity.

The actual amount of ice formed (see photographs) is far in excess of what seems possible by the hoar-frost theory. On January 7th the ice fringes formed on a single plant were collected and weighed. The ice formation on this plant, on this date, weighed over 5 grammes. The weight of the ice on the large sample shown in the photograph (Plates 8 to 11) is probably between 4 and 5 grammes.

FIG. 3.



In view of the fact that the stems are dry it is, of course, superfluous to consider the ice fringes to be composed of the "plant juices." The ice is tasteless, in spite of the fact that the plant has a strong fragrance of thymol.

Observations Showing How the Ice Fringe Grows.—One of the most interesting observations was the formation of the ice fringe from its very beginning. This was witnessed by several of my colleagues, who were called in to verify the observations. On a cold morning, February 16th, the samples in Test "B" were placed outside the laboratory window, and in about 20 minutes the ice fringe was observed to be forming. It consisted of a row of fine hairs extending up and down a length of about 4 mm. of the stem, and projecting out horizontally 0.2 to 0.3 mm. (see Fig. 3, *A*) These filaments were visible only when viewed against sky light, and they melted immediately on lifting the glass cover. The fringe did not appear to form at the line, Fig. 1,

where the pith is closest to the surface of the stem. This experiment was repeated again during the evening. Within half an hour after placing the samples (Test "B" with additional samples) in the cold air one stem showed several fringes in the form of thin, transparent "teeth," each one being about 12 mm. in length and about 1 mm. in height. Another stem showed a fine hairy fringe which was visible when viewed against a gas light. Within half an hour this hairy fringe appeared to be solid, with some of the fine hairs extending horizontally outward through the solid "tooth" of ice, as shown in Fig. 3, *B*. This, of course, is the general structure of the fringes. By the next morning numerous wide fringes had formed on these stems. In another sample the tooth of ice pushed out a narrow strip of bark similar to the illustration given in Fig. 3, *B*. In these tests the receptacle containing the water was small, and hence the whole cooled very rapidly and the water froze, which prevented the growth of the ice fringes. It is to be noticed that the ice fringe forms some distance up the stem, at a point where it cools the quickest and where the moisture has risen to about its maximum height.

Test "C," started February 17th, contained half a dozen samples of *Cunila* and a stem of an "aster" in a large test-tube. The test-tube was imbedded in wool to retard cooling and freezing. Within 15 minutes after placing this test outside of the laboratory window two small fringes, 1.5 mm. long and about 0.3 mm. high, were noticed when viewed against the sky light. This test was prolonged for some days and nights, and a photograph was taken (February 18th, Plate 12), showing that the stems, in water, form ice just as they do when attached to the roots In this photograph, which is magnified slightly (1.2), about one-third of the upper part of the largest fringe is broken off. These fringes appear a little more transparent than usual, owing to melting while taking the photograph.

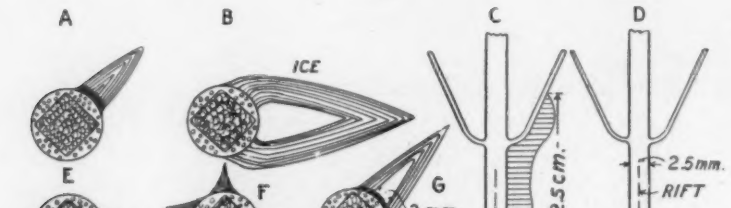
No ice or moisture was formed on the aster stem, which is in agreement with the field observations, where in only one instance was there an ice fringe found upon an aster stem. In this field sample of aster there was but little ice, which was very close to the ground. In Test "C" all the *Cunila* stems showed moisture, and ice was formed on nearly all of them. The thinnest stems formed the most ice.

Test "D," started February 17th, consisted of an assortment

of *Cunila* stems, ten in number, mounted in a large, wide-mouthed bottle, having a capacity of about 1 litre. This bottle was wrapped in hair felt, in a box, which was kept outside the laboratory window. The stems were supported as usual by the cardboard lid, which was thoroughly covered with paraffin. The protruding stems were covered as usual with a large glass beaker, which rested closely upon the felt.

As may be seen from Fig. 1 and Plates 4 and 5, the *Cunila* stem, on drying (shrinking), splits easily into four parts, owing to the small amount of wood fibre at the four sides of the stem. One of the samples used in Test "D" was a splinter, consisting of one-quarter of the stem, about 6 cm. in length, with a line of pith adhering to the inner side. On the following morning, and on subsequent days, this splinter showed a fringe of ice on the

FIG. 4.



woody surface, but at no time was there ice formed on the pith. One sample consisted of one-half of the stem, as shown in Fig. 4, *A*, and on February 20th a solid fringe or "tooth" of ice was found projecting out to a height of 3½ mm. It was about 2 mm. wide at the base and extended perhaps 1 cm. up and down the stem. An interesting feature (which to the writer became a common observation) was that the ice fringe did not always start at the "corner" of the stem where the wood is the thickest; neither did it start at that part of the stem where the wood is thinnest, but at a mid point, as shown in Fig. 4, *A*. From the microphotograph of a thin section of the stem it appears that the largest part of the ice fringe may form at the point where the sap tubes lie nearest the surface, hence where the moisture can be supplied the most easily.

Another sample in Test "D" consisted of a thin stem (1.5 mm. cross-section) which was split into four segments for a length of about 2 cm. The ends of the stem were intact. My notes, recorded on the morning of February 20th, state that "one can see through the cracks in the stem. Two ice fringes are formed, extending outward to a height of 7 mm., and extending 12 mm. vertically along the axis of the stem; but they are *not formed in the cracks.*" In fact, the point of attachment of the fringe to the stem, as examined under a reading glass, did not even extend close to the cracks.

In some of the samples in Test "D" the stems were entirely free from bark (see the photographs of Test "C"), while some were covered with bark. In the latter samples the ice pushed out a narrow strip (1 mm. wide) of bark, as shown in Fig. 3, *C*. This seems to be the usual manner in which the stems are stripped of bark. The bareness of the stem, however, does not seriously affect the ice formation, as may be noticed in the accompanying photographs. One sample had a fringe 3.5 cm. in length and 2 to 3 mm. thick at the base. When the bark is still intact, the ice formation appears to occur most frequently at the "corners" of the stem (see Fig 1). In the bare stems the ice was sometimes found (Test "D," February 17th) to be formed well around the stem, as shown in Fig. 4, *B;* and numerous field observations showed that this is the result of the fusion of two fringes, leaving a wedge-shaped free space between them. The commonest form, however, is shown in Fig. 4, *G* (field observations of January 6th and 8th), in which the ice ribbons were described as a composite of thin sheets which were estimated to be 0.3 mm. in thickness. The open space was perhaps 3 mm. wide at the base. The base appeared to be a solid shell 0.5 mm. in thickness. One could easily look through this wedge-shaped opening. Sometimes these fringes adhere well to the stem, so that the ribbon breaks across the open space. After sunrise the stem warms rapidly, which no doubt explains the ease with which the ice ribbon is usually separated from the stem.

The bare stems used in this test were old stalks from which the bark had been separated by previous ice formations in the woods. Evidently the laboratory test did not interfere with the ice formation. The roots are not necessary for the production of the ice fringes. As a matter of fact, the stalk and the nearby

roots are dead, although the rest of the plant (new growth) is perennial.

The ice usually formed on the flat side of the stem, but, as already mentioned, it often was found to cover the whole side, as shown in Fig. 4, *B*. In some stalks the ice "tooth" was found (note of February 17th) to have formed near the "corner" of the stem, as shown in Fig. 4, *A*. Other ice teeth were observed in the process of formation, as shown in Fig. 4, *E* and *F*, the ice being solid, about 3 mm. in length and half a millimetre in height. Fig. 4, *E*, was observed on Test "B," February 13th; and Fig. 4, *F*, was found in the field on January 11, 1914. In view of the fact that the general notion is that the stems are split by the frost, it is important to notice that in these laboratory tests none of the stems were rifted by the ice formation. The rifted stems used in these tests were samples which had cracked on drying and shrinking, after having been in the laboratory.

The ease with which these stems became saturated with water after having been drying for weeks is another item worth noticing. All the stems used in Tests "C" and "D" had been in the laboratory for some time. Some of them had been gathered in November, 1913, and had been freed of bark by previous ice formations.

It is generally supposed that the ice is formed more easily in the fall (when the plants are fresh) than in the late winter. This seems to be true, to some extent, according to my field observations and to my laboratory tests. In the latter, Tests "A" and "B," the ice did not seem to form so abundantly after the stems had soaked for some weeks. It seemed as though the sap tubes became clogged, or the plant had begun to decay.

Although the laboratory tests were continued after February 21st, no records were kept, and at the risk of being prolix the notes of the last two mornings are given herewith.

On February 20th (warm and rainy the first part of the night, cold and freezing in the morning) moisture and ice fringes were found extending 2.5 to 3 cm. up the stems. Test "C" contained 5 *Cunila* stems and one "aster" stem. Ice fringes were found on four of the five *Cunila* stems, but no ice or moisture was found on the aster stem. There were two to four fringes on each stem, some of the fringes being 1 cm. wide,—*i.e.*, extending outward horizontally 1 cm. from the stem. The last laboratory observations were made on the morning of February 21, 1914. Tests

" B," " C," and " D " were under observation, having, of course, been started the previous evening. Test " D " had ice fringes on seven of the nine stems of *Cunila*. The thick *Cunila* stumps did not seem to be able to form ice, and there was no moisture on them. Test " C " had ice fringes on all the *Cunila* stems (there were four stems), but no ice or moisture was on the aster stem. The aster is one of the common plants found growing near some *Cunila* stalks, but was so badly broken that it was not identifiable with any of the numerous asters which abound in the locality. Some stems had four fringes, but no ice was observed in the cracks which were in one of the stems. Some of the fringes were curled back against the stem.

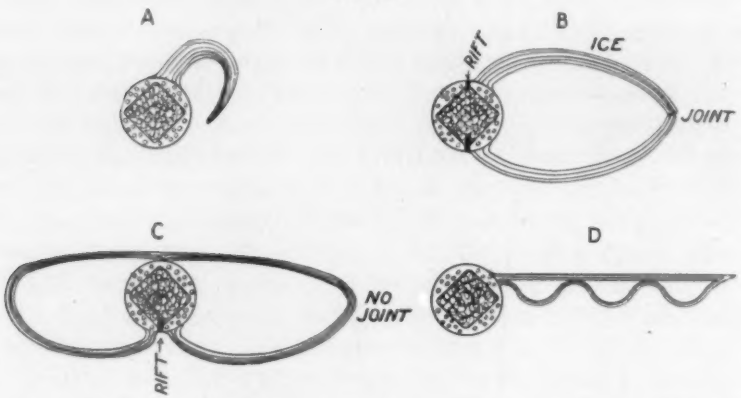
Test " B " showed ice fringes on two of the three stems under observation. The third stem was a very thick one, which showed a fine line of ice just starting. The fringes were small, being only about 3 mm. long and 2 to 3 mm. high.

The peculiarity of the fringes, on February 21st, was that in all three tests (" B," " C," and " D ") the fringes were small, and the outer edges were curved back against the stem, as shown in Fig. 5, *A*. This seems an interesting observation, for it serves to explain the peculiar ice loops one so frequently observes in the field. They no doubt start as a thin fringe (as in the laboratory test of February 21st), one side of which grows faster than the other, thus forming a curved fringe, as shown in Fig. 5, *A*, which in some cases seems to freeze against the stem. As more ice is formed the loop is merely enlarged, as shown in Fig. 5, *B*, which is a field observation (January 18, 1914) on a rifted stem where no ice was formed in the rifts. This loop was jointed at the ends. A still more remarkable formation (observed January 18, 1914) is shown in Fig. 5, *C*, which also showed no ice formed in the rift. In this sample it was especially noted that the loop was not jointed. A further illustration of the composite character of the fringe is shown in Fig. 5, *D* (field observation January 18th), in which one side of the fringe has intermittently grown faster than the other side, thus forming a wavy, fluted surface, while the other side is smooth. My notes of January 18th state that the loop is usually jointed at the outer edge (Fig. 5, *B*), the fringe usually starting near the rift.

These illustrations seem to indicate that the ice fringe has its beginning in a row or several rows of fine, hair-like filaments of

ice, as shown in Fig. 3, *A*. These filaments of ice, which remind one of the finest filaments of mold, increase in number, thus filling in the gaps, and form a continuous film of ice. They extend upward and downward along the axis of the stem; and they widen out, thus producing the sharp, wedge-shaped formation of ice which one finds in the early stages of growth of ice fringes. It is possible that when the plant is exposed in the open fields the fine, hair-like filaments of ice, which constitute the first stage of the fringe, are not formed, and that the thin, solid, tooth-like formation constitutes the beginning of the ice fringe. As shown by the laboratory test, however (Test "B" mentioned on a previous page), the ice fringe passed through both stages of growth. At

FIG. 5.



7 P.M., February 16th, the fine, hair-like filaments were visible. At 7.30 P.M. these filaments had multiplied and coalesced into a solid film, with hairy streaks in it, as illustrated in Fig. 3, *B*. The following morning the fringe had grown larger than the sample shown in the photograph (Plate 12) of Test "C."

These laboratory tests serve to explain the filamentous structure of the mature ice fringes, which are always found to be fibrous, the ice ribbon often breaking into several ribbons. This is well illustrated in the large ice fringe shown in the photograph (Plate 7) of Test "C." The light, horizontal lines show the edges of the individual fringes. In fact, this particular sample contained large, open spaces, in spite of the fact that it was not more than 2 mm. in thickness,—*i.e.*, the thickness of the stem.

The formation of the ice filaments (Fig. 3, *A*) might be used as evidence in supporting Le Conte's theory of a "projectile force" which produces the fringe. The difficulty then arises in attempting to find the cause of the projectile force. The physical forces now familiar to us seem sufficient to account for the phenomenon, without invoking unknown forces. These known physical activities are: (1) cooling of radiation, (2) a rapid capillary movement of water through the interior of the plant, and (3) sufficient moisture in the soil so that the capillary forces can bring moisture to the surface at a greater rate than that at which moisture passes into the air by convection and by evaporation. The capillary movement of water may possibly be accelerated by the temperature gradient in the stem, which is cooler on the outside.

The main difficulty in this explanation of the cause of ice fringes lies in the fact that the second stage in their formation is an apparently solid wedge of ice (see, however, Fig. 3, *B*), whereas the mature fringe is fibrous in structure, is very friable, and often separates into a series of thin, wide ribbons, as thin as tissue paper. This fibrous structure, however, may be the result of re-formation by variations in air temperature, by evaporation, etc., which produces the white fringe shown in the photographs. The laboratory formations never appeared quite so white. The great transparency of the sample, Test "C," shown in the photograph, Plate 12, is owing to melting while taking the photograph. The field specimens differ greatly in translucency. On a cold, frosty, cloudy morning (January 18th?), the atmosphere having a "damp" feeling, the numerous ice ribbons, 2 to 3 cm. in length, were conspicuous for their great transparency.

What Determines the Location of the Ice Fringe upon the Stem?—The ice fringe is usually found to adhere loosely to the stem. It seemed to continue to increase in size even when the ground surrounding the plant was frozen to a depth of 1 to 2 cm. As was found by Le Conte, the ice formation ceases its growth after the ground has become frozen to a considerable depth. The moisture in the stem is then found to be frozen, and ice is found in the (rifted) stems. On very cold mornings the ice fringe extended down to the ground (observation of January 11th). The closeness with which the fringe approaches the base of the stem depends, of course, upon the temperature of the ground.

The height to which the fringe can form seems to be governed by the rate of capillary movement of the water, and the rate of evaporation (and convection) from the surface. In the laboratory tests where the plants were covered and protected from the wind the moisture rose 5 to 6 cm. in the stem; but on removing the cover evaporation reduced this height to 1 to 2 cm. When the soil was wet the ice ribbons were the widest. For example, on January 7th a width of about 4 cm. (1½ inches) was recorded. After several days of cold and freezing, the ground having become quite dry, the ice fringe was short and did not rise more than 1.5 cm. above the ground. There is evidence that the ice fringe may form on a definite position of the stem. For example, one stem which on February 17th formed a large fringe on the "outside" (see photograph Test "C"), *i.e.,* near to the glass cover, was rotated 180 degrees. The next morning the ice fringe was found to have formed on the "inside," *i.e.,* on the same side of the stem, showing that proximity to the glass cover did not change the location of the fringe upon the stem.

The location and the amount of the ice formation are evidently determined by the ease with which the moisture can be supplied from within the plant. An examination of the cross-sections of plant stems showed that sap-tubes may be located very close to the outer wall of the stem. One would expect this to be the starting point and the most prolific source of production of the largest fringes. In the laboratory test-sample, the stem showing this property was one from which the bark had been scraped, and the abrasion may have been deeper on the side which produced the most ice.

In the field one strong, weather-beaten plant (stem without bark, 2.5 mm. in diameter), situated on a steep bank, was observed, all winter long, to form the ice fringe on one side. It was split as shown by the dotted lines in Fig. 4, *C,* but no ice was observed in the rift. Sometimes the base of the ice tooth was almost solid and embraced half of the stem, as shown in Fig. 4, *B.* After a rain, when the ground was quite wet, the ice fringe extended 2 to 2.5 cm. up the stem and out along a branch (observation of January 11th), as shown in Fig. 4, *C.* On other mornings when the ground was dry and powdery there was but little ice formed above the loose earth, which continued sliding down the steep, bare hillside. The ice fringe, however, whether a wide

ribbon or a short, wedge-shaped tooth, Fig. 4, *D*, half buried in the shifting dry ground, was always formed on the same side of the stem. The clump of (three or four) plants of which this was one stem never formed such long ribbons as was to be observed on other stems which were situated on a lower level on this same bank, where the ground was always moist. The plants of Test 2, described elsewhere, were located on the lower level of this steep hill, also stumps of *Cunila* from which the tops had been cut. No ice was observed to form on the cross-section of the stump; but long, curled ribbons of ice continued to form along the side of the stem which was on a level with the ground. The soil itself

Plate 6.

formed excellent samples of "ground ice." It was, therefore, an interesting sight to sometimes observe the ice fringes from the stumps of *Cunila* protruding out over the ground ice. The ground ice formed only after rain when the ground was wet, *i.e.*, contained a certain amount of moisture.

Description of Photographs of Ice Fringes.—The attempts at photographing the ice fringes as they occurred in the woods were far from satisfactory. This was owing to the fact that at 8 A.M. the illumination was low. A wide stop was used in the camera, and consequently the objects are in focus only in the centre of the photograph. They serve the purpose, however, to illustrate their general appearance as found in the woods. The ice fringes are viewed at an angle of almost 45 degrees. However, a general idea of the size of the fringes may be obtained

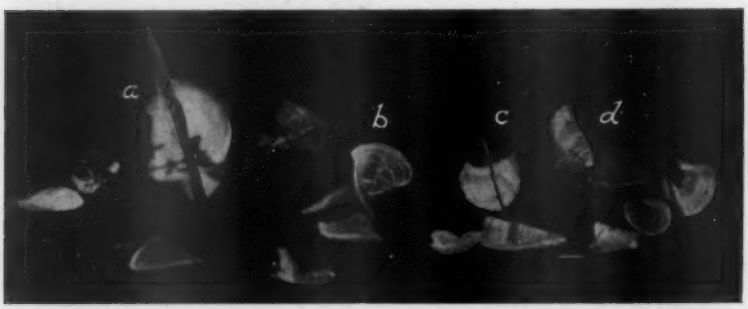
by comparing them with the accompanying pocket-knife, which is about 14 cm. in length.

The photograph, Plate 6, was obtained on January 7, 1914. It is typical of what one finds as regards size and general appearance of the ice fringes. The fringe in the lower left-hand corner

PLATE 7.

is composed of three whorls; the open space in the fringe nearest the knife is shown by the round dark spot in the centre. The brightest ice fringe in the stalk in the centre of the picture is not unlike the large sample shown in Plates 8 and 9. This photograph

PLATE 8.



shows seven stalks with ice fringes. One formation in the lower right-hand corner of the photograph is broken. The *Cunila* stalk upon which this fringe was formed (the stalk with the three branches) shows the bark pushed out at the base of the stem, with some ice still adhering to it.

Plate 7 was obtained in the middle of January. The ice formation in the centre of the photograph contains four beautifully folded fringes, the markings of which are, unfortunately, lost in the print.

PLATE 9.

The finest photographs (Plates 8, 9, 10, and 11) were obtained by collecting a number of ice fringes one cold, frosty morning (January 6, 1914) and having them photographed at the Bureau of Standards. Grateful acknowledgment is due Mr. E. D. Tillyer

PLATE 10.

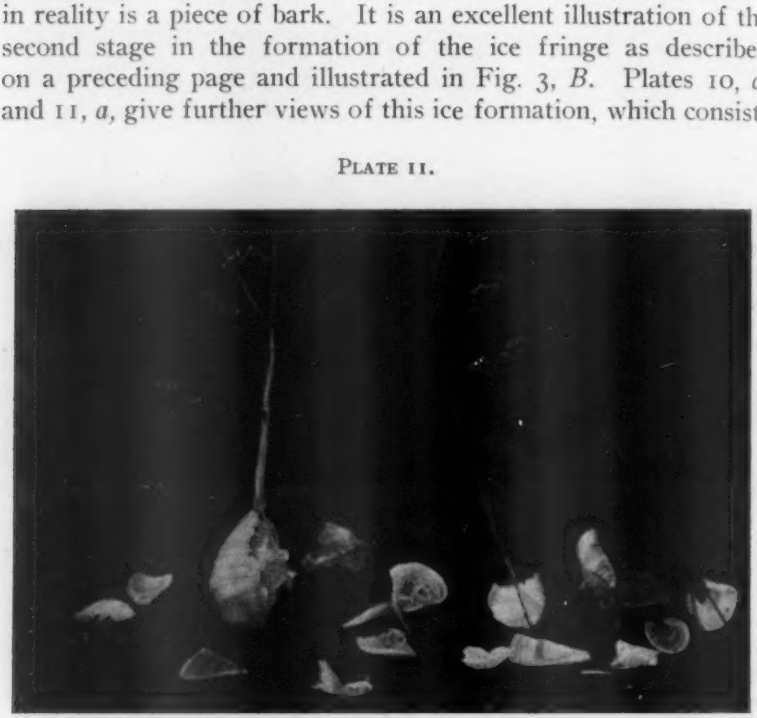
for his painstaking care in making these photographs, which no doubt are the finest records yet obtained of these beautiful ice formations.

In Plate 8 the four most conspicuous ice fringes are lettered *a*, *b*, *c*, *d*, which makes identification easy in Plates 9, 10, and 11.

In these plates the ice fringes were photographed from different sides. In Plate 8, *a*, it may be noticed that the stem is free from bark.

In Plate 9, *a*, an extremely thin, delicate fringe may be noticed protruding from what appears to be a rift in the stem, but what in reality is a piece of bark. It is an excellent illustration of the second stage in the formation of the ice fringe as described on a preceding page and illustrated in Fig. 3, *B*. Plates 10, *a*, and 11, *a*, give further views of this ice formation, which consists

PLATE 11.

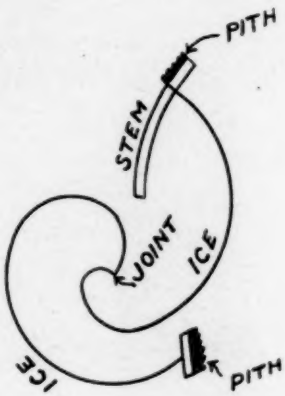


of two large fringes, twisted and whorled. In Plate 10, *a*, the oft-mentioned thin, wedge-shaped fringe (see Fig. 4, *E* and *F*) is shown to advantage, protruding (upwards in the photograph) from above the large fringes. The *Cunila* stalk *a*, shown in these plates, is typical of what one finds after several ice formations, when the stem is well stripped of bark. The stem is 2.2 mm. in diameter and it is not rifted. As shown in Plate 10, *a*, the "width" of the fringe adhering to the stem is 3 cm. It extends out horizontally 3 cm. from the stem. The distance from the stem to the extreme distal end of the loop is 4 cm.

Plate 8, *b*, consists of three splinters, united at the base of the

stem. They are, of course, the remnants of the stalk, which had long since disappeared. The dark line in the wood is the pith, which is shown to better advantage in Plate 11, *b*, and Fig. 6. Plates 9 and 10 show the pith side of another splinter. We thus have a photographic record of the ice formation, not only upon the unrifted stalk, but also of the formation of the rifted stalk (Plates 8, 9, 10, and 11, *c*) and of the formation upon the bare splinters. This is an unusually interesting ice formation. The peculiar whorl in the centre (Plates 9 and 10, *b*, are top views) is the meeting-point of two fringes (see Fig. 6), both of which began curving clockwise. The extreme thinness and the great transparency are to be noticed (see also Plate 3, *d*) by the light and the dark streaks through the fringes.

FIG. 6.

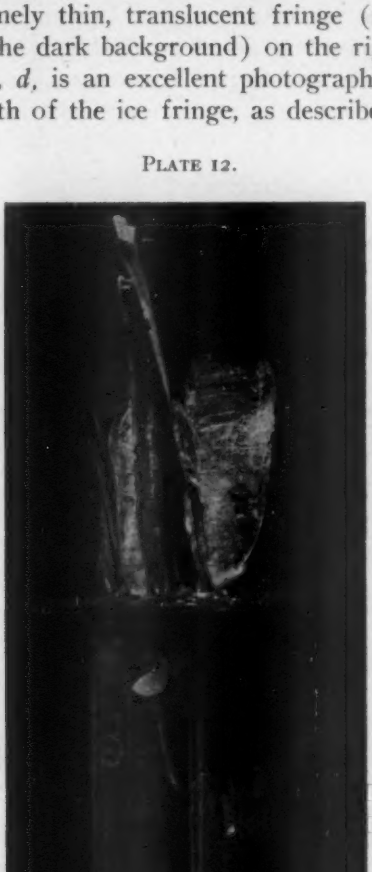


The small ice fringes on the stalk shown in Plates 8, 9, 10, and 11, *c*, are of interest because they occur upon a thin stem which is split into two parts, the rift being easily distinguished in the photographs. In fact, most of the rift is above the ice fringes. This ice formation is also conspicuous in having pushed out some of the bark, as illustrated in Fig. 8, *c*. This is an excellent photographic record showing that the ice is not formed upon the pith (Fig. 8, *b*) or in the rift of the *Cunila* stem.

Plates 8, 9, 10, and 11, *d*, give a further illustration of the formation of ice fringes upon fragments of stems of the *Cunila*. The sample is a very small one. The stump of the stalk had to be

cut out of the ground in order to obtain the fringes. Some of the ground is still adhering to the stem. One of the fringes is broken off. The extremely thin, translucent fringe (it appears to be dark, owing to the dark background) on the right-hand side of Plates 8 and 11, *d*, is an excellent photographic record of the manner of growth of the ice fringe, as described on a previous

PLATE 12.



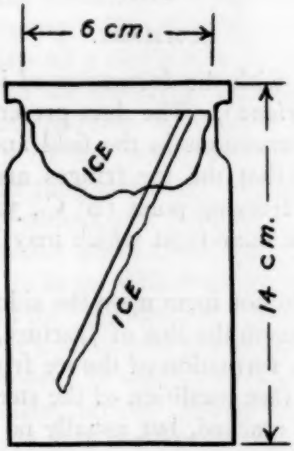
page. The growth of the fringe is along a straight edge, which appears almost horizontal in the photograph. This, however, is partly owing to the peculiar curvature of the fringe. The distal edge is straight and smooth, just as it started when near the stem. The photographic record is, therefore, an excellent contradiction of the hoar-frost theory of accumulation. In the tests with the asphaltum already described the ice fringe had a similarly

formed straight edge. The dark streak along the fragment of stem is pith. The ice fringe is upon the woody side of the stem.

Plate 11 shows the upper parts of the stem, a few leaves and the showy seed capsules. All the plates show fragments of ice fringes, the bright and dark streaks of which are owing to the difference in thickness and hence in transparency of the ice.

Plate 12 is a photographic record of the laboratory Test " C." It was taken by the writer February 18, 1914. The test-tube was about 20 mm. in diameter, which gives one some idea of the dimensions. The test is described on a preceding page. This

FIG. 7.



record is of interest mainly in showing that the *Cunila* stems, after having been in the laboratory for some months, form ice fringes, just as they do when attached to the roots.

Ice Formation in a Large Body of Water.—In view of the possibility that the ice formed at the bottom of a river (the Anchor ice mentioned at the beginning of this paper) may be owing, in part, to some other cause in addition to the high emissivity of the river bottom, it is desirable to call attention to a peculiar formation of ice as the result of cooling and refrigeration in a body of still water.

In Test " D," already described, the receptacle containing the water was a wide-mouthed bottle, 6 cm. in diameter at the top and about 14 cm. in height. The bottle was wrapped in hair felt and

tightly packed in a box. Cooling was therefore mainly by conduction and radiation from the top. On one occasion it was observed that instead of the ice freezing solid across the top, there were several extremely thin "curtains" of ice suspended in the water, as shown in Fig. 7. They were visible only in intense sunlight. Several thin, narrow, saw-toothed blades extended far down inside the bottle. They seemed to take the line along which refrigeration occurred, as a result of cooling, principally by conduction and radiation at the top of the vessel. It would be desirable to determine whether the density of these fine ice spicules is the same as that of a large mass of ice.

SUMMARY.

This paper deals with the formation of ice fringes upon the Dittany (*Cunila mariana*). The data presented are based upon experiments and observations in the field and in the laboratory.

It was observed that the ice fringes are formed when the temperature falls to freezing point (0° C., 32° F.); but they are not a function of the hoar-frost which may be present upon the ground.

The ice fringes do not form upon the side of a splinter which contains the pith or upon the line of fracture, but upon the outer woody surface. The formation of the ice fringe, however, is not a function of the surface condition of the stem. The stem is frequently found to be cracked, but usually no ice protrudes from the rifts.

The growth of the ice fringe ceases when the ground is frozen to a depth of 2 to 3 cm., and when the moisture in the stem is frozen.

The size of the ice fringes and the height to which they extend above the ground depend upon the rate of evaporation from the stem and upon the amount of moisture in the ground. Over 5 grammes of ice may be formed upon a single plant during a single night.

Photographs are given of ice fringes formed upon stems which had been kept in the laboratory several months. They show that the ice may be formed upon stems without the roots. Hence the ice is not formed as a result of hydrostatic pressure exerted by the roots, which are perennial.

All the observations are in agreement in showing that the moisture arises in the stem as the result of capillary attraction. The height (1 to 5 cm.) to which the moisture can rise within the stem is governed partly by the rate of evaporation from the surface.

Microphotographs of thin sections of plants are given, which show the structure of stems of plants which do not form ice fringes; also microphotographs of sections of stems of plants which form ice fringes. It is shown that those plants which form ice fringes the most readily and in the greatest abundance have the most sap-tubes.

The ice fringe is a composite of a number of very thin ribbons. In the laboratory the formation of the ice fringe was observed from its very beginning. The first stage in the production of the ice fringe consists of a single row of fine, hair-like filaments of ice. This row of ice filaments lengthens, up and down the stem. The filaments increase in number, thus forming a solid wedge-shaped tooth of ice, which constitutes the second stage of development. In the third stage of development the wedge-shaped tooth of ice widens and increases in length, as the result of freezing of the water which continues to soak out of the stem.

There appears to be no difference between the formation of these ice fringes and the "ground ice" formed on wet soils, other than that in the latter a particle of gravel usually forms the nucleus to start the congelation. In both cases the moisture is brought to the surface by capillary action. When the rate of supply to the surface is more rapid than the loss by evaporation, and the air is at a sufficiently low temperature, ice is formed.

WASHINGTON, D. C., June 25, 1914.

Phase Compensation. G. H. EARDLEY-WILMOT. (*Electrician*, lxxiii, 51.)—The different kinds of plant available for phase compensation are considered, such plant being classed as (1) that which may improve the power factor of the system as a whole, and (2) that which is applied to individual motors. The overexcited synchronous motor is first considered, the effects being illustrated graphically and by specific instance. Reference is then made to condensers, and, lastly, a case is taken where a rotary phase advancer is used. It is pointed out that the type of plant to be adopted must depend on the circumstances of each case, as it is impossible to lay down any general rule.

Paper Standards and Paper Testing. C. F. CROSS. (*Papier fabrik.*, xii, 831.)—The primary physical properties involved in paper testing are: In breaking strain, the sectional area; in specific volume-weight, the density or concentration of fibre substances. In testing for strength, the breaking strain should be referred not only to the unit of sectional area of the strip, but the results should also be calculated on the assumption that the area broken consists entirely of fibre substance without air space. The ratio of thickness of paper to absolute fibre density should always be kept in view. The suggestion by Briggs that breaking strain and volume, both referred to unit weight of paper substance, should be combined additively to give an expression for "handle" is criticised, the author's view being that any combination of the two factors mentioned above should be expressed as a product.

Wood-preserving Industry in the United States, 1913. (*Board of Trade* J., July 20, 1914.)—Returns from 93 wood-preserving plants, of which 58 are commercial plants and 35 private plants, 26 of which are operated by railway companies, show that in 1913 these plants treated 153,613,888 cubic feet of material, or 21.9 per cent. more than in 1912. The total consumption of creosote oil by these plants in 1913 was 108,873,359 gallons, an increase of 29.5 per cent. over the previous year; the consumption of zinc chloride amounted to 26,466,803 pounds, an increase of 27.5 per cent., and of miscellaneous liquid preservatives 3,885,738 gallons, an increase of 26.4 per cent. The quantity of creosote imported in 1913 was 62 per cent. of the total amount used. Plants for the manufacture of creosote oil are now being erected in the middle West, and, if present plans materialize, should add about 10,000,000 gallons annually to the available supply of creosote.

Tellurium as a Coloring Agent in Soda-lime Silicate Glass. P. FENAROLI. (*Chem. Zeit.*, xxxviii, 873.)—Tellurium, like sulphur and selenium, acts as a coloring agent in glass only under reducing conditions, in which case it may be present as a colloidal solution of the element, causing blue or brown colorations, or as a polytelluride which yields a red glass. In the blue glasses the colloidal particles are larger than in the brown. The absorption spectrum of the red glasses corresponds to that of aqueous solutions of polytellurides with a characteristic maximum between 480 and 490 $\mu\mu$. Comparing the members of the sulphur family, it is concluded that in combination with an alkali metal their staining power tends from yellow to red with increasing atomic weight; that they form colloidal solutions in glass more easily as the metallic character of the element increases, the analogy between selenium and tellurium being greater in this than between sulphur and either of them; and that none of them colors glass under oxidizing conditions.

PROGRESS IN INDUSTRIAL FELLOWSHIPS.*

BY

RAYMOND F. BACON, Ph.D.,

Director of Mellon Institute of Industrial Research and School of Specific Industries of University of Pittsburgh.

RELATIVE to the paper by Dr. Duncan on "Industrial Fellowships," which appeared in the JOURNAL OF THE FRANKLIN INSTITUTE in January, 1913, it is gratifying to be able to state that the system therein presented has since received a splendid recognition in the gift of over half a million dollars on the part of Messrs. Andrew W. and Richard B. Mellon, bankers and citizens of Pittsburgh, for its permanent establishment under the name of the "Mellon Institute of Industrial Research and School of Specific Industries of the University of Pittsburgh." Of the sum thus presented, $250,000 is being used for the construction of a beautiful, permanent building on the campus of the University; $60,000 was made immediately available for the purchase of permanent equipment in the form of apparatus and supplies, $20,000 for the purchase of the nucleus of a chemical library, and $40,000 a year for at least five years for maintenance.

The Mellon Institute thus established is an integral part of the University, with the exception that it has a special Board of Trustees, in the membership of which the University is represented, and that under this Board of Trustees it manages and controls its own funds and affairs; in all instructional matters it is in the closest relationship with the University.

The building, when completed, will afford ample accommodation for seventy researchers, it being thought advisable to limit the researchers to this number owing to the necessity, on the part of the administration, of keeping in the closest personal touch with the work of the individual researchers and the advisability of conserving the fraternal spirit of the organization. The building is being constructed so as to afford every possible facility conducive to a successful outcome of the researches concerned. The sum of $60,000 provided for the purchase of initial apparatus and supplies will insure, as well, the means for every researcher

* Communicated by the Author.

to go from what may be called the "test-tube" scale of experimentation to a scale sufficiently large to justify the industrial installation of a process.

In addition to the researchers thus provided for, the building of the Institute will afford ample accommodation for a Graduate School of Specific Industries; and, as this is altogether a new idea in education, I beg to explain it.

As the Industrial Fellowships which constitute the basis of this system are constantly increasing in amounts subscribed by the industrialists for their maintenance, and, as well, in their importance, it is, of course, obvious that the seventy researchers thus provided for will number among them men of national or international importance, to say nothing of the fact that as a class they are carefully chosen as picked men from the best institutions of learning and from the greatest industrial organizations in this country. Such a corps of workers will, therefore, be of the highest potential value as an educational staff for students fitted to receive such instruction. Enthusiastic young chemists who have received a thorough training in the fundamentals of the science and who desire to make their life-work in a certain industry may thus become thoroughly familiar with the application of chemistry to that particular industry—by being in intimate contact with those who are devoting their whole time to the problems of that specific industry. Thus, for example, the man who wishes to become an expert in *glass* will work in the laboratory and in the glass factory with those who have for a long time been devoting themselves to the problems of the glass industry and who are in the forefront of that industry.

The young man just out of school, going directly into the factory, is apt to encounter many conditions so discouraging [1] that unless he is of very exceptional calibre and unless he receives more than ordinary encouragement from those in charge of the business he may lose his enthusiasm and degenerate into a routine man and, perhaps, never be able to contribute anything to the upbuilding of that particular industry. American factories, as a rule, do not have adequate laboratory facilities for research, and too many American business executives do not appreciate the time and difficulties involved in prosecuting successful research. Many lines of business are so full of tradition and prejudice that

[1] Duncan, Robert Kennedy, *Jr. Ind. and Eng. Chem.*, vol. iii, 1911, p. 177.

serious obstacles are often deliberately put in the way of the young chemist by misguided workmen and superintendents to prevent his experiments from turning out successfully. Another point of considerable importance in this matter has to do with the organization of many American factories. While the higher executives of the company may thoroughly appreciate difficulties of research and the time often necessary for its successful prosecution, in the actual factory organization the chemist is very often placed immediately under and must report to some man who does not have such breadth of view. This man is often the factory superintendent, who may be chosen primarily because of his ability as a driver of men. The factory superintendent may tell the chemist to undertake a certain piece of research. In a few weeks—or sometimes even in a few days—he comes around to find out the result obtained. If no result is available, very often the chemist is shifted to other problems; or it may be that something unusual, which has just arisen, seems of pressing importance and the chemist is asked to drop everything else to take up the new matter. The net result is that after a few attempts by the young chemist to do big things, unsuccessful because the necessary uninterrupted time was not allowed, the factory superintendent reaches a conclusion that nothing can be gained by the research of the chemist and the chemist himself, if young and inexperienced, may lose his ideals [2] of research.

Under Dr. Duncan's system of Industrial Fellowships, the Mellon Institute and its Fellow have the sympathy and hearty coöperation of the higher officials of the corporation concerned; and yet in his work the Fellow is to a considerable extent independent of that corporation, as he is under the immediate control of the administration of the Institute. The Institute is thus able in many cases to push through to a successful conclusion large-scale experiments in the factories of the corporation which could hardly be accomplished by the company's own chemists. The young student entering the School of Specific Industries learns the difficulties which must be overcome in successful large-scale work, not only on the purely scientific and experimental side but also on the human side, and finds that by proper and tactful methods these human difficulties can be met; so that instead of

[2] Robert Kennedy Duncan, *Harper's Magazine*, February, 1913, vol. 126, pp. 385–90.

losing his first rush of enthusiasm he gains by actually seeing ideas and theories grow into commercial realities.

Such, in brief, is the idea of the School of Specific Industries. It is not the intention to go out after students for this school, nor is it the intention ever to have very many students in the school, but it is believed that the proper sort of young men will seek its instruction.

By the time that this article appears in print it is probable that the Mellon Institute will be operating in its new building. On its door is the following inscription, which expresses in a few words the ideal for which it is striving:

"This building is dedicated to the service of American Industry and to young men who destine their life-work to the Industries; the goal being Ideal Industry, which will give to all broader opportunities for purposeful lives."

In its equipment the Institute is somewhat different from the usual scientific laboratory. As a new process is but barely started towards commercial reality when it has passed the test-tube stage, the Institute has been very well equipped with unit apparatus for conducting chemical operations on a large scale; and in a broad sense the equipment of the Institute may be said to include the factories of the corporations which are using its facilities. The usual history of a new process as worked out in the Institute is somewhat as follows. The researcher conceives and works out this process at first with the usual apparatus of the scientific laboratory and by the same methods which are used in research in pure science, all the conditions affecting the reaction involved being determined with even more care and accuracy than is often necessary in a purely scientific investigation. The next stage is to perform the same reactions, still on a very small scale, but in apparatus which is constructed of materials which are available for larger scale work. To this end the Institute is well equipped with the usual standard large-scale apparatus for heating, distilling, drying, etc., and has, in addition, an excellent workshop with several trained mechanicians who build special small plants. After the difficulties of materials and of construction are solved, the next stage is either one of two things: (1) The equipment of the company's factory may be such as to permit a trial of the new process directly in the factory—and it has been found that American manufacturers are very willing to have such trials made when

the previous work has been of such a character as to indicate a reasonable chance of success; (2) or, in case the process demands apparatus of a new type, which is not available in the factory, a unit plant is built. This plant is of such a size and is built in such a way that when it is running smoothly the manufacturer will feel justified in taking over its plan and spending such money as will be necessary to put in a very much larger unit or, it may be, several units. I might say that the companies which are using the Institute have, during the past year, spent approximately $55,000 in building small unit plants to develop the processes which have been worked out in the laboratory. This does not include many processes which were adapted to the factory equipment already on hand. In no case was any of this money for plants provided for in the original foundation of the Fellowship, but in every case after conference the company felt that the progress of the work and the results obtained appeared promising enough to justify them in the expenditure of this money for further development. In the case of a number of these small plants in which processes have been developed, and where the processes have now gone into the commercial scale of operation, the plants are still available, being located in small, temporary buildings around the Institute; and such unit plants can often be adapted to the study of other new processes. The Institute is thus gradually acquiring what might be called a "large-scale equipment" that is undoubtedly unique in American laboratories. It might be well in this connection to say a few words as to just how the Fellowships which have been operating under this system are turning out. In a recent conversation with one of the foremost American technical chemists, who has built up more than one great industry on the basis of research done under his direction, this chemist expressed the idea that while he was firmly convinced of the practical dollar-and-cents value of research and he felt that a great many researches which would come to the Institute would ultimately yield such very large commercial returns as to justify the existence of such an institute, he was of the opinion, nevertheless, that many problems presented would be impossible of solution and that the donors of such fellowships would become discouraged, and that consequently, in the future, manufacturers might feel that while there was a chance for very large returns they would not be justified in spending the necessary money unless there was a considerable cer-

tainty of obtaining some return. Experience so far has shown that this was but a partial truth. A manufacturer will often present a problem which investigation proves to be so difficult as to be practically impossible of solution. It seems to be always the case, however, that, while the fellowship founded by a certain company may not be able to solve the original problem presented, there are so many other problems confronting manufacturers that very soon the problem is found which can be solved; and very often the manufacturer himself does not realize until after an investigation is started just what his problems are and just what improvements and savings can be made in his manufacturing processes. The net result of these facts has been that the fellowships are almost uniformly successful. I feel firmly convinced, from the experience in this work, that almost any manufacturer having a trained man give his whole time and attention to the problem and difficulties of his particular company, through the excellent facilities of the Institute and its accumulated experience in meeting such, is practically certain to reap a greater monetary return than the amount of money expended in the investigation, and that in very many cases he will obtain results of such far-reaching importance that the ultimate reward may be many times the outlay.

It is perhaps advisable to consider the relation of the Mellon Institute to the commercial chemist. In this connection I do not know how I could do better than to quote the head of one of the largest commercial laboratories in the country, who, in speaking on this matter, said: "Research is like dipping up the ocean with a spoon"—unending; the more good research that is done in this country the more will be the demand for research and the more will all chemical business be stimulated. The Institute does not attempt to take up any questions which might be denominated as of strictly routine character. It does no analyses and does no work that does not involve new things—that is, real research. It is not, therefore, in any sense a competitor of commercial laboratories, so far as the major portion of their work is concerned. There are now in this country a few commercial laboratories which are specializing in high-grade research work. In a certain sense the Mellon Institute might be considered as a competitor to these laboratories; looked at in a broader way, it might be con-

sidered as an advance sales-agent of all these laboratories, as one of the principal aims of the Institute is to demonstrate to manufacturers the value of research—and all good research will mean more and more research. It is getting to be a well-recognized principle in business that in the pioneer work of the introduction of a totally new class of products there will be, because of the multiplied publicity, more business for each of several firms than for one firm, especially where the product has a practically unlimited market, as in the case of research. And, of course, in its broader aim of making American industry more efficient in its manufacturing practices, the Institute will stimulate all American chemistry, as efficient industry means continual control in all stages of manufacture. No man can foresee what will be the ultimate end of a great idea such as that conceived by Professor Duncan and developed by him into the Mellon Institute. It is fairly well recognized that the experimental stage has long since passed, and I have attempted in this article to give the present status of the work and to explain some of the manifold relations of this system to industry and to science.

For the sake of the scientific world, it is perhaps unfortunate that the results obtained under these Fellowships may not be published at once; while the agreements under which Industrial Fellowships are founded provide for eventual publication, this can be done only at such time as will not unduly injure the interests of the donating companies. It will be recognized by all, however, that those who pay for the investigations should own the results. For that reason, most of the important work done in the Institute to date has not yet been published. Many of the by-paths which appear in every investigation yield results of scientific interest, and a number of papers detailing the results of work of this character have been published by the Institute, a list of which is herewith appended.

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Selenium Glasses. O. N. WITT and FRÄNKEL. (*Sprechsaal*, xlvii, 444.)—Referring to Fenaroli's work, a knowledge of the colloidal nature of the coloring agent is regarded as less important than the proportion of selenium introduced to that which actually stains. The total selenium present was estimated by the amount of iodine it liberated from potassium iodide after the glass had been treated with hydrofluoric acid. The chromogenic selenium was estimated colorimetrically by comparison with a colloidal solution obtained by reducing selenium dioxide with gelatin and phosphoric acid. The figures obtained were: Selenium introduced, 0.0262; Se found, 0.021; chromogenic Se, 0.0016 per cent., a proportion of 100:8. Temperature influences the color obtained; at 620° C. a selenium glass was rendered colorless, but returned to its original tint on cooling. In glasses containing potash the color tends to brown, the more basic the composition. If potash be completely replaced by soda, a selenium glass is colorless. The maximum content of selenium in alkali-lime glasses is said to be 0.06 per cent.; above this limit volatilization occurs. In alkali-lead glasses a much higher content is possible, owing to the formation of lead selenide, which colors the glass dark brown. As selenium in the free state begins to volatilize at 120° C., it should be introduced as selenite or selenate. In the subsequent discussion the use of selenium as a coloring agent in the ceramic industry was approved and recommended.

Thermo-electric Power of Tin Selenides. H. PÉLABOU. (*Comptes Rendus*, clviii, 1897.)—SnSe forms a couple with platinum in which the current travels from the platinum toward the selenide across the hot junction. With temperatures of 0° and 100° C. the potential difference is –0.033 volt, and for temperatures of 0° and 580° C. it is –0.2 volt. $SnSe_2$ gives values of the same magnitude but of opposite sign up to 600° C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A VIBRATION ELECTROMETER.

By Harvey L. Curtis.

[ABSTRACT.]

ANY alternating current measurement which makes use of a null method requires an instrument which will detect small alternating currents or voltages. One of the first instruments used for this purpose was the telephone. This is very sensitive between the frequencies of 500 and 3000 cycles per second, but at frequencies below 500 cycles the sensitiveness decreases rapidly with the frequency, so that it is very insensitive at frequencies below 100 cycles. It also responds to the harmonics of the current as readily as to the fundamental.

As a null instrument, a vibration galvanometer is often much more satisfactory than a telephone. The moving system of a vibrating galvanometer is adjusted to have the same period as that of the current to be detected, so that any harmonics in the current produce very little effect upon the deflection of the instrument. Also, most vibration galvanometers have their maximum sensitiveness at low frequencies (50 to 200 cycles), though at least one form may be had which will go to frequencies as high as 3000 cycles. Since the impedance of these instruments is relatively low, they require an appreciable current to produce a deflection which can be observed. Hence in bridges where the impedance of the arms is very high they are not very sensitive.

The vibration electrometer described in this paper was designed as a vibrating instrument having an impedance much higher than a telephone or vibration galvanometer. The need arose in connection with the measurement of some very low capacities at low frequencies. Its usefulness is limited to those cases where it is desired to detect very small currents at low frequencies. Its principal use is as a detecting instrument in a bridge having very high impedances in the arms.

The instrument is a modification of a quadrant electrometer. Instead of the quadrants there are four vertical plates, while a thin vertical vane of twice the area of a single plate corresponds

* Communicated by the Bureau.

to the needle of the electrometer. Two plates, separated by a narrow vertical slit, are in one plane, while opposite them in a parallel plane are the other plates. Midway between the planes is the aluminum vane which is suspended by a bifilar suspension. This vane is maintained at constant potential by a battery, while an alternating voltage having the same period as the natural period of the vibrating system is applied to the plates. This causes mechanical forces to be applied to the vane due to electrostatic attractions and repulsions which will set the vane in vibration. Since these forces are small, it is necessary that the damping shall be small. In addition to so designing the suspension that there is very little loss of energy in it, it is necessary to keep the instrument in a vacuum.

The form of the instrument is such that the capacities can be approximately computed. Hence it is possible to develop the mathematical theory of its behavior. This has been done, and the conclusions reached have been checked by experiment. The important conclusions are as follows:

1. The frequency at which maximum deflection is obtained depends upon the potential of the vane. As the potential of the vane is increased, the frequency at which maximum deflection is obtained is decreased.

2. The deflection for a given voltage is inversely proportional to the damping.

3. As the damping is decreased, the tuning becomes sharper.

4. The power required to give unit deflection when the applied electromotive force is in resonance with the instrument decreases in the same ratio as the damping.

Experimentally it has been found that the instrument will detect a current as low as 10^{-12} ampères.

ELECTRICAL RESISTANCE AND CRITICAL RANGES OF PURE IRON.*

By G. K. Burgess and I. N. Kellberg.

[ABSTRACT.]

THE exact determination of the variation of the electrical resistance of pure iron (99.98) in terms of temperature has been made over the range 0 to 950° C., particular attention being

* Scientific Paper.

given to the form of the curve over the A2 and A3 critical ranges. It was found possible to adapt the apparatus for determining heating and cooling curves described in Scientific Paper No. 213 to the determination of the resistance of iron in terms of that of platinum by the medium of a very sensitive Wheatstone bridge and the above-mentioned cooling apparatus. The iron and platinum thermometers were enclosed side by side *in vacuo* within a quartz tube, and it was possible to determine the resistance curve to a precision of 1 in 1,000,000 or to 0.005° C. No anomalies are found in the resistance of iron until the A2 region is approached, and at A2 there is an inflection at 757° C. in the resistance temperature curve shown as a sharp cusp in the temperature coefficient. At Ac3 the resistance of iron falls abruptly by some 0.005 of its value, which is recovered within a 25° interval, and above Ac3 it increases greatly again. On cooling, the Ar3 is accompanied by slight increases of resistance with falling temperature. Ac3 and Ar3 begin at the same temperature, 894° C., and each extends over a temperature interval of 25°. These resistance measurements show that A2 is a strictly reversible transformation and A3 is a transformation taking place at a higher temperature on heating than on cooling. These experiments are in agreement with the thermal observations previously recorded in Scientific Paper No. 213.

Whether or not either or both of these critical ranges A2 and A3 are to be considered allotropic points will depend upon the definition of allotropy, about which there does not appear to be agreement.

THE HYDRATION OF PORTLAND CEMENT.

By A. A. Klein and A. J. Phillips.

The study of the hydration of Portland cement follows as a natural sequence to the study of its constitution. The latter has been determined by the work of the Geophysical Laboratory on the ternary system lime-silica-alumina, and for that portion of the ternary field in which Portland cement is situated these compounds have been verified by the Pittsburgh laboratory of the Bureau of Standards.

In the present paper various hydration experiments were made on monocalcium aluminate ($CaO.Al_2O_3$), 5:3 calcium alu-

minate ($5CaO.3Al_2O_3$), tricalcium aluminate ($3CaO.Al_2O_3$), mono-calcium silicate ($CaO.SiO_2$), beta-ortho-silicate ($2CaO.SiO_2$), gamma-ortho-silicate ($2CaO.SiO_2$), and tri-calcium silicate ($3CaO.SiO_2$), lime burned at different temperatures and ground to various degrees of fineness, and on the following commercial cements, a high silica, a low silica, a high iron, and a high magnesia cement.

The tests consisted of (1) hydration on microscopic slides with water, without access of air; (2) hydration with superheated steam in a cylinder, according to the method proposed by Bied; (3) hydration in an autoclave, and (4) moulding with limited quantities of water, approximating those used in normal consistency mixes. Lime water and plaster-of-Paris solution were also used as hydrating mediums. Petrographic methods were employed to determine the hydration processes and the final products.

The only crystalline product observed in the hydration of the aluminates was hydrated tri-calcium aluminate ($3CaO.Al_2O_3.xH_2O$), and this is only formed with a large excess of water. It crystallizes in hexagonal needles, plates, and spherulites, and is uniaxial positive. The refractive indices are = 1.552 − .003 and = 1.535 − .003. The 5:3 calcium aluminate and mono-calcium aluminate split off amorphous hydrated alumina and form the crystalline hydrated tri-calcium aluminate. The hydration of the aluminates commences quickly in all cases, but with restricted amounts of water the unhydrated grains become coated with the amorphous form and further hydration is more or less retarded, this amorphous form slowly changing to the crystalline form. With steam at atmospheric pressure the weakly basic aluminates do not hydrate above 110°, but the more basic ones absorb water up to 140°, tri-calcium aluminate containing high-burned free lime absorbing water even at 175°.

The hydration of the aluminates in lime water reveals no new products, but in plaster solution, in addition to the same compounds formed with water, there is a compound observed with a formula $3CaO.Al_2O_3.3CaSO_4.xH_2O$ — tri-calcium sulpho-aluminate, usually referred to in cement literature as "sulpho-aluminate." This compound is identical for three aluminates and crystallizes in long prismatic needles. The double refraction is low, the character of the principal zone negative, and the extinction

parallel. The indices of refraction are less than 1.48. It is biaxial positive with a large optic axial angle. Its formation is only incidental in the retardation of the initial set caused by gypsum. In the autoclave, crystals of both the sulpho-aluminate and gypsum are destroyed.

Burned lime hydrates with an excess of water to either the crystalline or amorphous form of lime hydrate. A preponderance of the former is produced where the lime is coarse and high-burned, while the formation of the amorphous form is favored by fine grinding and low burning. Crystallized lime hydrate occurs as flaky hexagonal crystals or as hexagonal prisms with excellent cleavage parallel to (.0001). It is uniaxial negative and the refractive indices are $=1.581-.002$ and $=1.559-.002$. In the autoclave amorphous lime hydrate does not change to the crystalline form, but free lime may yield crystals of hydrate whose size depends upon the length of time of reaction, temperature, and pressure.

The mono-calcium silicate and the gamma-ortho-silicate do not hydrate, while the beta form of the latter hydrates but slightly with water after long periods. Lime water and plaster solution do not materially increase the hydration, whereas a solution of the calcium aluminate gives the maximum hydration and best-appearing test pieces. The 28-day test pieces of beta-ortho-silicate and the aluminates, while exhibiting fairly good rigidity, have by no means the strength of corresponding neat cement briquettes. The aluminates are completely hydrated, but the beta-ortho-silicate shows only a comparatively slight hydration. The hydration product of the silicate is amorphous hydrated ortho-silicate, there being no lime hydrate split off and no needles of hydrated mono-calcium silicate formed, as noted by others.

The tri-calcium silicate hydrates readily and quickly with all concentrations of water, the products of hydration being crystallized lime and amorphous hydrated ortho-silicate. Moulded specimens set hard in 5 hours and show no disintegration after 28 days in water. It has no favorable effect on the hydration of beta-ortho-silicate. Mixtures of it and the aluminates show first the beginning of hydration of the aluminates, followed shortly by the hydration of the silicate. Moulded specimens of these are dense, hard, and strong, comparing very favorably with neat cement briquettes.

On the hydration of cement, the first constituent to react is the aluminate, with the formation of amorphous hydrated tri-calcium aluminate, with or without amorphous hydrated alumina. The sulpho-aluminate crystals are also formed, and the low-burned or finely-ground lime hydrates. This occurs within a few hours after the cement is gauged. The next compound to hydrate is the tri-calcium silicate. This commences within 24 hours, and is generally completely hydrated within 7 days. Between 7 and 28 days, the amorphous aluminate commences to crystallize and the beta-ortho-silicate, the least reactive compound, begins to hydrate. The 24-hour strengths are due mainly to the hydration of the aluminates and of any fine-grained, low-burned lime present. The large increase in strength between 24 hours and 7 days is due mainly to the tri-calcium silicate hydration. The increase between 7 and 28 days is due to the hydration of the beta-ortho-silicate. Where there is a decrease in strength during this period it is due to the hydration of very high-burned free lime, as in very high-burned, high-limed cements, or to the crystallization of the aluminates, as in high alumina cements. The iron compounds in a cement are resistive to hydration. It does not form crystalline hydration products, but occurs as a rust-like material.

The initial set of cement is affected by the action of small amounts of electrolytes in retarding coagulation of the aluminate material. With a limited amount of water, such as used in normal consistency mixes, the aluminates coagulate and separate from supersaturated solutions as amorphous bodies, the rate of coagulation being affected by such small quantities of electrolyte as to nullify the possibility of the reaction being solely a chemical one.

Failure of cement in accelerated tests is due to the growth of large lime hydrate crystals. The disrupting action results from the pressure caused by growing crystals. Cement will fail in the boiling test which contains lime sufficiently fine and high burned, so that during boiling it hydrates and crystallizes. The growth of crystals is sufficient to cause disintegration. When a cement passes the boiling test but not the autoclave test, it contains lime so coarse or high burned as not to hydrate in the boiling test, but only in the autoclave, due to the high temperature and pressure employed. Some cements will pass either test only after aging. In this case aëration with insufficient water to allow solu-

tion and crystallization causes the lime to hydrate as amorphous hydrate, and in the accelerated tests there is no crystallization and no disintegration.

The reactions when cement is subjected to the autoclave test are not abnormal. The disintegration action attributed to the crystallization of the sulpho-aluminate has been greatly exaggerated.

THE LEAD ACETATE TEST FOR HYDROGEN SULPHIDE IN GAS.*

By R. S. McBride and J. D. Edwards.

The effect of the following factors upon results obtained in tests for the detection of hydrogen sulphide in gas by the lead acetate test have been investigated: (1) The paper: Kind; method of its preparation, including the strength of lead acetate solution used; and the moisture content when used. (2) The gas: Its humidity, and the period and rate of flow. (3) The apparatus: Its form and size, as determining the circulation of gas with respect to the paper. With gas mixtures containing various known amounts of hydrogen sulphide these several factors were studied one at a time and the following conclusions reached.

An operator, by giving consideration to the desirable qualities which are pointed out, can easily select the most suitable and convenient kind of paper after a trial of a number of samples; the convenience, but generally not the accuracy, of the test is affected by the choice. There is little or no difference in the sensitiveness of the paper prepared with lead acetate solution from 2 to 12 per cent. in strength; a 5 per cent. solution is recommended. Treatment of the papers with ammonia or carbon dioxide does not materially change their sensitiveness. It is recommended that the test paper be dipped in lead acetate solution, blotted, and used moist, since such paper gives the most reliable results.

The large effect of the humidity of the gas upon the test results is shown; but it is also noted that the use of moist paper with short test periods (not over 3 minutes) gives results practically independent of the humidity of the gas. It is impracticable either to dry or to saturate the gas to a constant condition

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* Technologic Paper 41 of the Bureau.

as to humidity, because of the probability of simultaneous change in the hydrogen sulphide content.

The rate of gas flow is shown to have some effect, but increases in rate produce less effect than proportional increases in the time of test. The general practice of making tests at 5 cubic feet per hour is satisfactory; maintenance of the rate within the limits 4.5 and 5.5 cubic feet per hour is sufficient.

The time of test is an important factor in determining its sensitivity; the proper basis for selection of the length of test is treated in connection with the discussion of the quantitative and engineering significance of the test.

The different forms of testing apparatus used may be classified into three groups—circulating, impinging, and penetration—these being distinguished by the manner in which the gas is brought into contact with the paper. The five forms of circulating apparatus tested were: The simple hydrogen sulphide tester, chosen for this work and designated in this paper as standard apparatus; the Referees apparatus; the Young's sulphur and ammonia test apparatus; the small drying-tower form; and a large Woulff bottle. Only one very simple form of the impinging type was tested; and a single penetration apparatus, devised by the authors, was used.

The variation in the test with different forms of apparatus is largely due to the variation in intensity of the gas currents and their direction in relation to the paper. In the small drying tower the test paper was suspended close to the rubber stopper bearing the burner, and a much larger proportion of the gas came in contact with the paper than in the other forms of apparatus. Although the Woulff bottle had a larger capacity than the Referees apparatus, it consistently gave a stronger test than the latter, showing that size alone is not a determining factor; the shape of the apparatus and the location of the paper relative to the inlet and outlet have an important influence.

It has been generally recognized that a test in which the gas impinges on the paper is more sensitive than one in which the gas does not impinge; this is due to the better opportunity for contact of the gas with the reagent on the paper and to the small area within which the lead sulphide is concentrated. And a similar increase in sensitiveness is accomplished by causing the gas to be tested to pass through the paper, as is done in the penetration

apparatus described. This increase in sensitiveness due to impingement of gas on paper seems to have been overestimated by some, however.

The important influence of the shape and size of the apparatus upon the result of tests made with it makes clear the necessity of an exact specification of the form and size of the tester. It is therefore recommended that the specifications given for the apparatus which is used as standard in this work be followed exactly in making the tests.

When the test is made under definite conditions, the coloration produced is of quantitative significance, as indicating the amount of hydrogen sulphide present in the gas. The results which are obtained by the procedure recommended as standard are shown to have the following significance: The test, if of 1 minute duration, will detect about 0.3 to 0.4 grain hydrogen sulphide per 100 cubic feet of gas. But if the test is of 0.5 minute duration, about 0.45 grain of hydrogen sulphide is required to give a test; if extended to 3 minutes, a gas of about 0.2 grain will give positive results. The Young's apparatus is slightly more sensitive than the standard form, but the Referees apparatus is less sensitive, for it will scarcely detect 0.5 grain of hydrogen sulphide per 100 cubic feet of gas when used with moist paper for 3 minutes at a rate of 5 cubic feet of gas per hour.

The penetration apparatus is somewhat more sensitive than any of the forms of circulating apparatus. The sensitivity of the apparatus of the impinging type is variable, depending upon the rate of gas flow, distances of jet from paper, etc.; but under the most favorable conditions apparatus of this type is the most sensitive of all.

No direct comparison can be made with the work of some of the previous observers, but it is certain that too great a sensitivity has been ascribed to the procedures used by these experimenters.

The commercial significance of the testing procedures recommended is pointed out. It is stated that many tests of similar severity, and some a great deal more severe, have been met regularly in the past, showing that the proposal is certainly not unreasonable.

The method recommended for use is quick and convenient and gives reproducible results; and a simple and inexpensive form of apparatus is described which can easily be constructed by

inexperienced persons without any sacrifice of the advantages due to exactness of specifications. The importance of conforming with the specifications, both as to the apparatus and the procedure in testing, is pointed out.

MEASUREMENT OF TIME AND TESTS OF TIMEPIECES.*

THE test and certification of watches, chronometers, and other timepieces has been carried on for many years at the Kew Observatory in England, at the Besançon Observatory in France, and at the observatories of Geneva and Neuchatel in Switzerland, but no such tests have been made for the public in this country, except for a few years at Yale University, many years ago. This line of work is now started at the Bureau of Standards, and a circular under the above title is being issued, giving the regulations under which the tests will be made, the methods employed, together with sections on the use and care of watches, and on standard time and the sources of reliable time standards with which one may make frequent comparisons of his watch. This first edition of the circular announces the regulations for the test and certification of watches only; the test of other timepieces will be taken up later.

For the purposes of test, watches are divided into two classes, designated as A and B, adapted to watches adjusted for five positions and three positions respectively. The former test lasts 54 days, the latter 40 days. Both tests include a test of the temperature compensation of the watch, at temperatures of 5°, 20°, and 35° C. In the Class A test is also included an examination of the isochronism adjustment of the watch. Four tests a year are carried out, beginning on the second Tuesday in January, April, August, and October respectively. The daily rates of the watches under the various conditions are determined within about 0.1 second. If the performance of a watch is within certain tolerances set for the different conditions, a certificate is granted showing the results of the test. If a watch fails to meet the requirements, a report is rendered showing wherein it fell short of the tolerances and giving its actual performance in the trial. Watches may be submitted by manufacturers or jobbers of

* Bureau Circular No. 51.

watches, by retail dealers, or by the individual owners of the watches, a fee being charged which is estimated to cover the actual cost of the test. It is expected that the tests will be especially valuable in cases where watches are to be used for scientific purposes or exploration, and also to purchasers of high-grade watches in giving them assurance that the watch is reasonably adjusted and in good condition at the time of test. Copies of the circular and also of the application blank which must be filled out by those submitting a watch for test may be obtained upon request directed to the Bureau of Standards, Washington, D. C.

Collision of α-Particles with Light Atoms. C. G. DARWIN. (*Phil. Mag.*, xxvii, 499.)—The large angle deflections of α-particles led to Rutherford's hypothesis of atomic constitution, but his calculations involve the assumption that the atom is so heavy as to remain sensibly unaffected by the collision. The author modifies and extends Rutherford's work by removing this restriction. Calling M the mass of the particle, and m that of the atomic nucleus, there are three cases to consider, according as m is greater than, equal to, or less than M, when γ is the number of α-particles with deflection φ observed within a solid angle ω, an expansion is obtained for γ as a function of φ and M/m, and in powers of the latter. *First case:* $m > M$. This applies to all substances except helium and hydrogen. The first term of the expression gives Rutherford's expression. If M/m were as high as $1/3$, as it would be for carbon, the velocity of the carbon nucleus might rise as high as $V/2$, V being the initial velocity of the α-particle. Such a particle might possibly be perceptible, but it is doubtful whether the shock would free the nucleus of all its electrons; thus the experimental conditions to reveal it are rather hard to imagine. *Second case:* $m = M$. The α-particle now travels through helium. In this case no particle can be deflected through more than a right angle, and to the number of α-particles must be added the He-atoms which have been set in motion so as to strike the screen, for the recoiling particles should be quite indistinguishable from the true α-particles. *Third case:* $m < M$. The α-particles travel through hydrogen, and $m = M/4$. The number of particles, as observed by the scintillations, will be composed of particles of three types, slow α-particles, fast α-particles, and the recoiling H-particles, which will move more rapidly than either of the other groups. In passing through matter these will be retarded like α-particles, and Bohr's formula shows that the range of an H-particle will be slightly less than an α-particle of the same initial velocity. Bohr's formula ceases to hold for small velocities, but Geiger's empirical formula $V^3 = V^3_0(1 - X/R)$ leads to the conclusion that, corresponding to a range of 31 cm.

of an α-particle, the range of an H-particle will be 28 cm. If an α-particle from RaC at its highest velocity strikes a nucleus straight on, the initial velocity of the H-particle will be $8/5 \times 2 \times 10^9$ cm. per second, and its range comes out at 117 cm. It would probably be greater than this, as at high speeds the range should be more nearly proportional to V^4 than to V^3. The H-particles, therefore, should be easily observable if they can be made to occur in sufficient numbers. Their scattering should be greater than for α-particles, for the most probable angle of scattering depends upon E/M, and so is twice as great for H- as for α-particles. Geiger and Marsden's experiments are strongly confirmative of the nuclear hypothesis, and no force proportional to the power of the distance other than the inverse square can give the observed relation between γ and V. An upper limit to the size of atomic nuclei is calculated from the distance of closest approach between the α-particle and the nucleus. For gold the number of deflections was observed up to $\varphi = 150°$, and found correct. Taking the charge of the nucleus as 100 times the electronic charge, and $V = 2 \times 10^9$ cm. per second, gives 3.5×10^{-12} cm. as closest approach. In a straight-on collision with an H-nucleus it would be 1.7×10^{-13} cm., which leads to the result that the radii of the nuclei H and He are certainly less than 10^{-13} cm.

Two New Modifications of Phosphorus. P. W. BRIDGMAN. (*J. Amer. Chem. Soc.*, xxxvi, 1344.)—Ordinary white phosphorus is converted into another modification, white phosphorus II, at about $-76.9°$ C. under atmospheric pressure, the change being reversible; the crystalline form of the product is probably hexagonal. A second modification—black phosphorus—is irreversibly formed by heating white phosphorus to 200° C. under a pressure of 12,000 Kilos per square centimetre. Black phosphorus has a density of 2.691, is not spontaneously inflammable, and is a fairly good conductor of heat and electricity. It has a lower vapor pressure and probably a somewhat higher melting-point than red phosphorus; red and black phosphorus appear to yield identical liquids when melted.

Action of Radium Rays on Bakelite. C. E. S. PHILLIPS. (*Nature*, xciii, 295.)—A disc 4.2 mm. thick of the light yellow variety of transparent bakelite was cut from a rod, polished, and then radiated with β- and γ- rays from radium. The color of the disc darkened to a wine-red after three days, and exhibited an absorption band λ- 5700 to 6000, which was not visible at first. The spectrum beyond λ 4900 Å. was also obliterated. The coloration extended to a depth of 2 mm., and it could be completely removed by exposure to a temperature of 100° C. for about three hours. The effect appears due to the direct action of the β- rays, and the author suggests that the new substance may prove to be a useful filter for therapeutic use, especially as it is cleanly and easy to work.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, October 21, 1914.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 21, 1914.

VICE-PRESIDENT COLEMAN SELLERS, JR., *in the Chair.*

Additions to membership, 22.

Mr. George R. Henderson, Chairman of the Committee on Science and the Arts, reported the condition of the committee's work.

The Chairman then introduced Dr. L. A. Bauer, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C., who presented a communication on "The Earth, a Great Magnet." The speaker gave the chief facts and latest results pertaining to the earth's magnetism, based largely upon the general magnetic survey of the earth, begun by the Department of Terrestrial Magnetism of the Carnegie Institution in 1904 and now two-thirds completed. The cruises of the non-magnetic ship *Carnegie* and the instrumental appliances and methods used in the observational work were described. An account was also given of the various expeditions sent under Dr. Bauer's direction to distant and more or less unexplored countries. The lecturer discussed the possible bearing of researches in terrestrial magnetism on other mooted questions in terrestrial and cosmical physics.

Experiments and lantern slides were used to illustrate the subject. The Chairman conveyed the thanks of the audience to the speaker.

The meeting then adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, October 7, 1914.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 7, 1914.

MR. L. E. LEVY, *Chairman pro tem.*

The following reports were presented for first reading:

No. 2584.—The Humphrey Pump.

No. 2595.—Dr. W. W. Strong's Dust, Smoke and Fume Indicator. Advisory. Adopted.

The following report was presented for final action:

No. 2605.—Blonck Boiler Efficiency Meter. Certificate of Merit. Adopted.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A stated meeting of the section was held in the Hall of the Institute on Thursday, October 1, 1914, at 8 o'clock P.M., with Dr. Harry F. Keller in the chair. One hundred and fourteen members and visitors were present. Dr. Max von Recklinghausen, of the R. U. V. Company, New York City, delivered an address on "The Ultra-Violet Rays and Their Application for the Sterilization of Water." The various sources of ultra-violet light were discussed, and a detailed description was given of the construction, mode of operation, and light emanations of the mercury-vapor quartz lamp. The physical, chemical, and biological phenomena produced by ultra-violet rays were enumerated, as were the various methods of measuring the rays physically, chemically, and biologically. The history of the application of the rays for the sterilization of water was traced; and the development of modern apparatus for this purpose was described, together with the results obtained on a commercial scale.

The paper was discussed at length, a vote of thanks was extended to Dr. von Recklinghausen, and his work referred to the Committee on Science and the Arts. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Mining and Metallurgical Section.—A joint meeting of the American Society of Mechanical Engineers and the Mining and Metallurgical Section of The Franklin Institute was held in the Hall of the Institute on Thursday, October 8, 1914, at 8 o'clock P.M.

Prof. H. E. Ehlers, member of the society, and Prof. A. E. Outerbridge, Jr., president of the section, presided jointly.

Professor Outerbridge introduced the speaker of the evening, Mr. J. E. Johnson, Jr., Consulting Engineer and Metallurgist, New York, N. Y., who presented a paper entitled "Recent Developments in Cast Iron Manufacture."

Mr. Johnson discussed the results of carbon, silicon, sulphur, phosphorus, oxygen, and manganese in cast iron. He outlined investigations, made at the Ashland Plant of the Lake Superior Iron and Chemical Company, in which it was disclosed that the presence of oxygen accounted for the superiority of charcoal iron over coke iron. He described experiments made to introduce oxygen into iron and convert coke iron into a product he considered superior to charcoal iron, and gave the physical properties of an iron of composition: Combined carbon, 0.85 per cent.; graphitic carbon, 2.65; manganese, 0.26; phosphorus, 0.326; sulphur 0.039; silicon, 1.25; oxygen, 0.50. Photomicrographs of the structure of this iron were shown.

The paper was discussed by several members present.

A vote of thanks was extended the speaker and the meeting adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

Section of Photography and Microscopy.—A joint meeting of the Photographic Society of Philadelphia and the Section of Photography and Microscopy was held in the Hall of the Institute on Thursday evening, October 15, at 8 o'clock.

Dr. Henry Leffmann, president of the section, occupied the chair.

The Chairman reviewed briefly the work of the section and called attention to the important papers on photographic subjects to be presented during the present season as part of the programme of lectures arranged by the Secretary of the Institute.

He then delivered a lecture on "Recent Advances in Photographic Chemistry." He showed some early slides made by impressing woodcuts on the surface of gelatin and enclosing the latter between sheets of glass. He illustrated the effects produced on sensitized plates by exposing them for a length of time in the dark near, but not touching, various metals and some other substances, such as quartz, collodion, etc. He described the production of photographs of printed matter, using luminous plates as the source of light.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

MEMBERSHIP NOTES.

Elections to Membership.

(*Stated Meeting, Board of Managers, October* 14, 1914.)

RESIDENT.

MR. R. B. CAVERLY, 529 Lincoln Drive, Germantown, Philadelphia, Pa.

MR. LESLIE M. WEBB, Wedge Mechanical Furnace Company, Greenwich Point, Philadelphia, Pa.

NON-RESIDENT.

MR. R. C. M. HASTINGS, The International Telephone Company, Columbus Savings and Trust Building, Columbus, Ohio.

MR. JOHN V. H. DORR, 30 Church Street, New York, N. Y.

Changes of Address.

MR. WALTER ATLEE, 2112 Eighteenth Street, Washington, D. C.

MR. JOHN CALDER, 25 Merriam Street, Lexington, Mass.

MR. EDWARD C. CARTER, 412 Greenwood Boulevard, Evanston, Ill.

MR. HAROLD V. COES, The Sentinel Automatic Gas Appliance Company, New Haven, Conn.

MR. F. WINSOR EVELAND, 6307 Sherwood Road, Philadelphia, Pa.

MR. PENROSE R. HOOPES, 1015 South Farragut Terrace, Philadelphia, Pa.

MISS EMILY E. HOWSON, Lake Erie College, Painesville, Ohio.

MR. E. KELLER, 720 Jefferson Avenue, E., Detroit, Mich.

MR. HUGO LIEBER, 14 Platt Street, New York, N. Y.

MR. FRANK M. MASTERS, 101 Park Avenue, New York, N. Y.

MR. J. W. WALKER, Port Kennedy, Pa.
MR. TINIUS OLSEN, The Gladstone, Eleventh and Pine Streets, Philadelphia, Pa.
MR. ALLEN WOOD, 3rd, Flat Rock, N. C.

NECROLOGY.

Mr. Henry Brinton, 2408 Bryn Mawr Avenue, Bryn Mawr, Pa.
Mr. J. Clifford Brooks, care of Philadelphia Electric Company, 1000 Chestnut Street, Philadelphia, Pa.
Prof. W. L. Dudley, Vanderbilt University, Nashville, Tenn.
Mr. Alfred Jones, The Wadsworth, Boston, Mass.
Mr. Arnold Nacke, 240 South Ninth Street, Philadelphia, Pa.
Mr. Kurt W. Peuckert, Sharon Hill, Delaware County, Pa.

LIBRARY NOTES.

Purchases.

American Electrochemical Society.—Transactions, vol. 25. 1914.
BUEHLER, F. A.—Filters and Filter Presses for the Separation of Liquids from Solids. 1914.
COX, JOHN.—Mechanics. 1909.
HALSEY, F. M.—Railways of South and Central America. 1914.
HOFMAN, H. O.—General Metallurgy. 1913.
HORNER, JOS. G.—Practical Iron Founding. 1914.
IVENS, EDM. M.—Pumping by Compressed Air. 1914.
LEBLANC, MAX.—Text-book of Electrochemistry. 1913.
MINERAL INDUSTRY, volume 22. 1913.
RANDALL, J. A.—Heat—A Manual for Technical and Industrial Students. 1914.
STROHM, RUFUS T.—Oil Fuel for Steam Boilers. 1914.
WAGNER, FREDERIC H.—Cleaning of Blast-furnace Gases. 1914.

Gifts.

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H. T. Paiste Company, Catalogue No. 20. Philadelphia, Pa., no date. (From the Company.)

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Sturtevant Company, Catalogue No. 150, Fuel Economizers and Air Heaters, July, 1911; Catalogue No. 210, Steam Turbines Booklet, "How the Chief Engineer was Convinced," May, 1913. Boston, Mass. (From the Company.)

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Western Electric Company, Modern Methods in Train Despatching. New York, no date. (From the Company.)

Western Society of Engineers, Year Book. Chicago, Ill., 1914. (From the Society.)

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Wetzel Mechanical Stoker Company, Catalogue. Trenton, N. J., no date. (From the Company.)

George D. Witcomb Company, Mechanical Methods of Mining, Air Hammer Drills. Rochelle, Ill., no date. (From the Company.)

Wisner Machinery Company. Leaflets on Steam Power Plants, Catalogue of Lanza Portable and Semi-portable Engines. New York, no date. (From the Company.)

Williamson, R., and Company, Sales Book No. 21, Lighting Fixtures. Chicago, no date. (From the Company.)

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Yarnall-Waring Company, The Log Book of the Power Plant. Chestnut Hill, Philadelphia, 1914. (From the Company.)

CORRESPONDENCE.

8 SUMMIT STREET, CHESTNUT HILL,
October 5, 1914.

MY DEAR DR. OWENS:

I was so much impressed with the artistic excellence and beauty of the bronze copy of the new Franklin Medal which I saw to-day that I cannot refrain from sending you a note of congratulation upon the acquirement for the Institute of such a valuable addition to the list of awards for important discoveries in science now in the gift of The Franklin Institute.

This medal fills a gap which I have long thought existed, and combines high artistic merit with intrinsic value, making it one which will enhance the reputation of the donor and recipient alike.

I am, yours truly,

(Signed) ALEX. E. OUTERBRIDGE, JR.

BOOK NOTICES.

INTRODUCTION TO ORGANIC CHEMISTRY, by John Tappan Stoddard. Philadelphia, P. Blakiston's Son & Co., 1914. 408 pages, illustrations, 12mo. Price, $1.50 net.

This book contains a large amount of information in a compact form. It is intended, as stated in the preface, to be used in connection with lectures and laboratory work. It will probably be of much use in the preparation of students intending to enter professional schools, for which an elementary knowledge of organic chemistry is required. The subject-matter follows the usual classification, beginning with the Hydrocarbons and passing to the more complex Compounds. A good deal of information is given as to certain practical bearings of Organic Chemistry.

The work is well written and well printed.

HENRY LEFFMANN.

TENNANT AND WARD'S MANUAL OF PHOTOGRAPHIC PROCEDURE. New York, Tennant & Ward, 1911. 6 volumes, 12mo. Price, 25 cents each.

As the publishers have not given these books a general or serial number, nor indicated the authors, we may describe them collectively by the above title. They are paper-covered "brochures" of about three-score pages each, six in number, giving information about flashlight photography, enlargements, development, outdoor work, dark-room manipulation, and home picture-taking. They have evidently been prepared by practical and skilled workers, and will be aids to amateurs in many ways. In the description of the testing of the safety of dark-room lights it would be well to mention that ordinary emulsions are much more sensitive when dry than when thoroughly soaked with developer.

HENRY LEFFMANN.

METALLURGY, by Henry Wysor. Second edition. Easton, Pa., The Chemical Publishing Company, 1914. 391 pages, illustrations, 8vo. Price, $3.

There are two distinguishing and meritorious features apparent in this text-book:

First.—It is thoroughly well balanced; that is to say, the twenty-nine separate chapters, covering a wide range of subjects, are so evenly proportioned that criticism on the score that the author has unduly elaborated one branch at the expense of another is completely disarmed. This is a common fault in books of this character.

Second.—There is a total absence of redundancy or "padding." Careful examination enables the reviewer to say that there is not a paragraph that could be omitted without loss of continuity or clearness.

It goes without saying that many things have been omitted which the student must know before he can claim the title of "expert," but it is impossible to give many details in a book of less than four hundred pages covering the general principles of metallurgy.

In his preface the author says: "Every teacher knows that his most ardent and painstaking efforts will be futile if he fails to enlist the students' interest—the beginner needs perspective rather than detail, breadth rather than depth, and when given a view of the subject as a whole and shown something of its meaning, his mind will submit more willingly, if not zealously, to abstraction and detail."

As a former teacher the reviewer can fully endorse this statement, and he congratulates the author upon having produced an exceedingly interesting book, holding the attention of the reader from beginning to end.

Moreover, the text is clear, concise, and up to date, modern electrical processes of steel making and electrolytic methods of refining metals are given, and the final paragraph refers to the latest and most curious "spray process" of depositing metallic coatings on wood, glass, or metals, the invention of M. U. Shoop, of Switzerland, in which the covering metal is atomized and shot out of a pistol in the form of a fine spray with great force, forming, it is said, an adhesive covering of uniform thickness. Objects of wood, metal, or glass may be even coated with aluminum in this way, also with steel. Hitherto it has been difficult, if not impossible, to coat any surface with aluminum or with steel.

This book is especially designed for students, but it is worthy of a place in the library of metallurgists and scientists generally.

A. E. OUTERBRIDGE, JR.

THE HALFTONE PROCESS, by Julius Verfasser. Fifth edition, revised and enlarged. 390 pages, 8vo. London. Iliffe & Sons, Ltd.

The use of halftone illustrations in connection with letter-press in books, magazines, and newspapers, and in commercial publications of all kinds, has become so extensive as to bring the production of this class of photo-engravings to the position of a considerable and growing art industry. The method of production is dealt with more or less fully in treatises on the photo-chemical reproductive arts generally, but in view of the importance of

the halftone process a work specifically devoted to this one subject presents a desirable addition to its literature.

The author, Mr. William Gamble, well known as the editor of the monthly publication, *Process Work*, and of the "Process Year Book," writing under a *nom de plume*, deals with his subject from the standpoint of the practical operator almost exclusively, only so much of the theoretical data relating to it being included as is requisite to afford the worker a proper insight into the process. The nature and peculiarities of the halftone negative, the various kinds of cross-line and grain screens used in its production, and the method of applying the screen in the making of the negative, are described in clear and simple terms and copiously illustrated. The same is true regarding all the other appliances required in the process, from the camera to the proofing press, each of these being considered in connection with the arrangement and outfitting of the several workrooms. A chapter devoted to a detailed consideration of the materials required in the process completes the first part of the book and forms virtually a preface to the second.

In Part II the author deals with the chemical operations incident to the halftone process, including the making of the negative, the sensitizing of the metal plate, the printing of the negative on the metal, and the etching of the plate, keeping in view constantly the needs of the everyday worker and affording him full information regarding matters of practical importance.

This present edition of the work is enlarged by a chapter on recent improvements of the product by means of etching machines, another on the details of the three-color halftone process, and one on the production of halftone illustrations by photo-lithography and the offset press.

A short and concise statement regarding the preparation of the copy for reproduction by the halftone process and various mechanical appliances for this purpose completes the work, which, as already indicated, has been thoughtfully prepared to meet the needs of the halftone photo-engraver. Equally careful, however, appears to have been the avoidance of a date mark anywhere in the book, a growing practice in connection with manuals of this character which is strongly to be deprecated.

L. E. LEVY.

PUBLICATIONS RECEIVED.

U. S. War Department: Annual Reports, 1913. Vol. i, The Secretary of War, The Chief of Staff, The Adjutant-General, The Inspector-General, The Judge-Advocate General, The Chief, Quartermaster Corps, The Surgeon-General, The Chief of Ordnance, The Chief Signal Officer, The Chief of Coast Artillery; vol. ii, Report of the Chief of Engineers (without appendices); vol. iii, Reports of Department Commanders—Eastern Department, Central Department, Southern Department, Western Department, Philippine Department, Hawaiian Department, Commanding General, Second Division, Military Academy Superintendent, Military Parks—Chickamauga and Chatta-

nooga, Gettysburg, Shiloh, Vicksburg; vol. iv, Reports of the Chief, Bureau of Insular Affairs, Philippine Commission, Governor of Porto Rico. 4 volumes, illustrations, tables, plates, maps, 8vo. Washington, Government Printing Office, 1914.

Canada, Department of Mines, Mines Branch: The Copper Smelting Industries of Canada, by Alfred W. G. Wilson, Ph.D., Chief of the Metal Mines Division. 184 pages, plates, maps, 8vo. Ottawa, Government Printing Bureau, 1913. Lode Mining in Yukon: an Investigation of Quartz Deposits in the Klondike Division, by T. A. MacLean, M.E. 205 pages, illustrations, plates, maps, 8vo. Ottawa, Government Printing Bureau, 1914.

Experimental Studies in Electricity and Magnetism, by Francis E. Nipher. 73 pages, illustrations, plates, 8vo. Philadelphia, P. Blakiston's Son & Co., no date. Price, $1.25.

U. S. Bureau of Mines: Bulletin 83, The Humidity of Mine Air, with Especial Reference to Coal Mines in Illinois, by R. Y. Williams. 69 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1914.

Aëronautical Society of Great Britain: Technical Terms Committee, List of Terms. 2 pages, folio. London, Society, September, 1914.

Explosibility of Grain Dusts: Comparative Investigation by Millers Committee of Buffalo, N. Y., under the direction of Dr. George A. Hulett, Chief Chemist, U. S. Bureau of Mines. A preliminary report by David J. Price and Harold H. Brown. 59 pages, illustrations, 8vo. Pittsburgh, Pa., July, 1914.

Philadelphia Department of Public Works: Annual Report of the Director for the Year Ending December 31, 1913. 48 pages, 8vo. Philadelphia, issued by the city.

Examination of Lubricating Oils, by Thomas B. Stillman, M.Sc., Ph.D., late professor of engineering chemistry in the Stevens Institute of Technology. 125 pages, illustrations, plates, 8vo. Easton, Pa., Chemical Publishing Company, 1914. Price, $1.25.

Practical Handbook for Beet-Sugar Chemists: Rapid Methods of Technico-chemical Analyses of the Products and By-products and of Material Used in the Manufacture of Beet-Sugar, by Werner Moeller-Krause, sugar chemist. 132 pages, illustrations 8vo. Easton, Pa., Chemical Publishing Company, 1914. Price, $1.25.

Ogden's Steam Separator. ANON. (*Mech. Eng.*, xxxiii, 403.)—In this apparatus for separating steam from water and oil the steam is passed through small curved tubes in a casing; the outer circumference of the tubes is perforated with several holes with their edges bent in oppositely to the direction of motion of the fluid, so that the oil and water projected centrifugally from the steam are passed out into the casing, the steam passing on alone into the delivery pipe to which the separator is connected. Two forms of the apparatus are illustrated.

CURRENT TOPICS

Electro-deposition of Nickel. C. W. BENNETT, H. C. KENNY, and R. P. DUGLISS. (*Journ. Phys. Chem.*, xviii, 373.)—Calhane and Gammage, in their investigations of the electro-deposition of nickel from a solution of nickel-ammonium sulphate, using commercial nickel anodes, found that the current efficiency was greater with stationary than with rotating kathodes, while the amount of iron deposited as impurity increased when the kathode was rotated. The authors have confirmed these results, and, in the light of further experiments, give a satisfactory explanation of them as follows: From the solution of nickel-ammonium sulphate, which is neutral or slightly acid, hydrogen will be deposited first on the kathode. The solution in the neighborhood of the kathode consequently becomes alkaline, and then, and only then, can nickel be deposited. Thus the efficiency of the deposition of nickel depends on the maintenance of an alkaline kathode film; stirring the electrolyte removes this alkaline film more or less completely, depending on the efficiency of the stirring, and thus the current efficiency diminishes. It was further shown that the efficiency can be started high and maintained high by adding a definite amount of ammonium hydroxide to the solution. The fact that the iron content of a deposit formed on a rotating kathode is greater than that formed on a stationary electrode is probably due to mechanical occlusion of the precipitated iron hydroxide from the alkaline solution. The iron content of the anode does not materially affect the efficiency.

Electrical Transmission of Power on Diesel-motor Ships. A. RASSMUSSEN. (*Elektrotechn. Zeitschr.*, xxxv, 468.)—Refers to methods by which subsidiary apparatus, such as capstans, are worked by electrical power. The main question refers to the suitable regulation of such auxiliary motors, and the author notices three methods. All the machinery is considered to be operated by series motors, and the first method consists in inserting a resistance in the magnet circuit, so that with a nearly constant current and torque it is possible to allow of heavy loads without blowing fuses, the motor under these conditions being merely brought to rest. The second method puts a resistance in parallel with the magnets, which avoids obvious difficulties that might arise from the heavy currents carried by the windings. The third and simplest plan consists in displacing the brushes, which works well if the currents are not too heavy. The case of the Diesel ship *Seelandia* is taken as a case in point, and figures are given relating to the suggested application of the author's system on board that ship.

Inflammability of Mixtures of Methane and Various Gases. LEPRINCE-RINGUET. (*Comptes Rendus,* clviii, 1999.)—The upper and lower limits of inflammability were determined for mixtures containing methane and oxygen in the constant proportions, $CH_4 + 2O_2$, and also varying amounts of nitrogen, carbon dioxide, and water vapor. The effect of added nitrogen was to lower the upper and raise the lower limit until the two coincided at a point corresponding to the composition: ($CH_4 + 2O_2$) 20.1 per cent. and N 79.9 per cent. The effect of carbon dioxide was similar, but of different magnitude, 0.56 volume of carbon dioxide having an effect approximately equal to that of 1 volume of nitrogen. The effect of water vapor could also be represented in a similar manner, so that if the mixture, temperature, and humidity are known, all necessary facts as to the inflammability can be deduced from a single diagram.

Automatic Mercury Pump. KLEIN. (*Journ. de Physique,* iv, Ser. 5, 293.)—This pump differs from older ones of the same type in that the gases, instead of being evacuated directly into the atmosphere, are passed into a canal system connected with a column of water, and, instead of the displacements of the mercury being produced by displacements of the receiver, they are produced by the receiver being put in communication automatically alternately with the atmosphere and with the column of water by a suitable arrangement. Diagrams are given showing the connections of the parts; and the method of working, together with the rate at which the gases are removed, is dealt with in detail.

Principle of Similitude. R. C. TOLMAN. (*Phys. Rev.,* iii, Ser. ii, 244.)—Presents some considerations which appear to have validity throughout the field of physical science. These conclusions are drawn from a single postulate or new principle, which may be stated as follows: The fundamental entities out of which the physical universe is constructed are of such a nature that from them a miniature universe could be constructed exactly similar in every respect to the present universe. This is called the *principle of similitude.*

The fundamental postulate is a relativity principle, *viz.,* the principle of relativity of size. In the body of the paper it is shown that relations must hold between the changes of lengths, masses, time intervals, energy quantities, etc., in order to construct the miniature world in question.

Potash Salts in Spain. (*Board of Trade J.,* July 9, 1914.)—Extensive deposits of potassium sulphate and carbonate have been discovered near Condona, 40 miles northwest of Barcelona. The deposits are of great thickness and begin about 200 feet below the surface.

Electrical Steering of Vessels. H. L. HIBBARD. (*Amer. Inst. Elec. Engin. Proc.*, xxxiii, 703.)—The modern steam steering gear is briefly described; among its disadvantages the author mentions: (1) Long lengths of steam piping and lagging, and rises in temperature of spaces through which the piping passes. (2) Wastage of steam, as steam steering gear takes full stroke, and the valve setting is often such that steam is always blowing through the engine. (3) The engine must be designed for the maximum work required of it,—*i.e.*, when the rudder is at the maximum angle. (4) Severe stresses on reciprocating parts due to sudden decrease of load when the rudder returns to the central position. Mechanical connections from the bridge to the engine valve are a continual source of trouble.

Against these the advantages of the electrical drive are: (1) Reduction of weight and space occupied by driving mechanism. (2) Suppression of heat in compartments. (3) Elimination of accidents due to burst steam pipes. (4) Reduction of vibration and noise. (5) More efficient mechanism, and the overload capacity of the motor can be used in extreme positions of the rudder. (6) Simplification of the control from the bridge. (7) Increase in rapidity and accuracy of response of the rudder to movements of the controlling mechanism.

A short description is given of the early electric gears, and a full description of the recent equipments put into United States battleships, including special contractors for the automatic control of the motor. The method is given for calculating the horse-power required to be installed.

Paper Pulp in the United States. V. E. NUNEZ. (*Papierfab.*, xii, Festheft, 41.)—The sources of supply for paper pulp are diminishing so rapidly that new sources must be sought for. In ten years, from 1900 to 1909, the consumption of pulp-wood in the United States increased by 100 per cent., the increase in home-grown spruce being 35 per cent. and in imported spruce 162 per cent. At present only one-third of the pulp-wood consumed in the United States is home-grown, and the present supplies in this country will probably be exhausted in thirty years. On the other hand, much progress has been made in the utilization of other species of wood which have hitherto been considered inferior for pulp-making. Balsam fir has been found to be a fairly satisfactory substitute for spruce in the manufacture of mechanical pulp for newspaper, while jack-pine and hemlock yield lower-grade mechanical pulp suitable for cheap qualities. Tests are being made with several other varieties of wood available in large quantities in the Western States. The inferior woods are preferably ground in admixture with spruce; fir wood tends to give a free coarse pulp of inferior color to that of spruce; the yield per cord is less, owing to the density of the wood. In the south progress has been made in the utilization of lumber waste, chiefly from long-leaf pine, for the manufacture

of a kraft-cellulose by the sulphate process. It is estimated that sufficient of this waste is available for the production of 10,000 tons of paper per day. There is also a large supply of stumps of black gum wood (*Nyssa sylvatica*), which yields a short-fibred pulp of the poplar class. Large amounts of Douglas fir are still untouched on the Pacific slope in the north. Of the minor sources of supply of paper-making material, sugar-cane refuse, previously shredded and largely freed from "pith" by the Simmons process, is considered the most promising. Fibrous waste from the sisal plantations of Yucatan is also available in substantial quantities, and yields paper pulp of excellent quality. Cotton-seed, hull fibres, and flax straw are capable of development in their respective classes. Corn (maize) stalks, sawgrass, cotton stalks, and many other plants are under investigation, but do not promise so well as the materials previously mentioned.

Production of Explosives in the United States during 1912. A. H. FAY. (*U. S. Bureau of Mines, Technical Paper* 69.)—The total production of explosives in the United States during 1912, according to the figures compiled, was 489,393,131 pounds, or 244,696 short tons. This product is divided as follows: Black powder, 230,233,369 pounds; "high" explosives (dynamite, nitroglycerin, dynalite, gun-cotton, etc.) other than permissible explosives, 234,469,492 pounds; and permissible explosives, 24,630,270 pounds. The total production is tabulated by States, and by kinds of explosives. Another table shows the total output of coal, with the corresponding amount of explosives used in its production. The amount of coal produced per pound of explosive varied from 0.86 ton in the group represented by Arkansas, Oklahoma, and Texas to 5.82 tons in Maryland and Virginia. One hundred and thirty-three men were killed in coal mines by explosives during 1912, and 134 in 1911. In 1902 the quantity of 11,300 pounds of permissible explosives was used in coal mining, whereas in 1912 the quantity so used was 18,150,618 pounds. The total amount of explosives used for the production of coal in 1912 was 226,142,043 pounds. The use of permissible explosives in coal mining has had gratifying results, and few, if any, serious accidents can be attributed directly to their use. In 1912 about three-fourths of the permissible explosives manufactured were used for coal mining. The reports of manufacturers of fireworks and ammunition are not included.

Pitchblende Discovery in India. (*Morning Post*, July 4, 1914.)—Deposits of pitchblende have been discovered in a pegmatite to the east of Banekhap, in the Gaya district of Bihar. At present between 8 and 9 hundredweight have been raised. Samples contained 83.39 per cent. of U_3O_8, and 260 to 315 milligrammes of hydrated radium bromide per metric ton.

Application of Producer Gas to Brass Foundries. E. F. BULMAHN. (*Trans. Amer. Inst. of Metals,* vii, 288.)—The use of producer gas for melting brass, for drying cores, and for power purposes in the brass foundry is advocated. It is essential that the gas be free from tar. At the Langsenkamp-Wheeler Brass Works, Indiana, an installation of four Westinghouse double-zone suction producers, each having a capacity of 500 pounds coal per hour, has been in operation for four years with satisfactory results. In the double-zone producer the raw fuel (bituminous coal) is carbonized in the upper section, and the residual incandescent coke converted into gas in the lower section. The gas is drawn off between the two sections and serves to generate steam in a vaporizer arranged around the top of the lower section: it is free from tar and is ready for use after passing through a wet coke scrubber and a dry scrubber. The gas has a calorific value of 110 to 115 B.T.U. per cubic foot, and in order to obtain the required temperature in the furnace, 2500° to 2600° F., or 1370° to 1430° C., both the gas and air are preheated by the waste gases from the furnace. Curves are given showing the relative cost of producer gas compared with ordinary lighting gas and with oil fuel. In melting red brass with producer gas the loss of metal was reduced to 0.75 to 1 per cent.

Tungsten in Bolivia. G. W. WEPFER. (*Eng. and Min. J.,* xcvii, 1251.)—Approximately 90 deposits of tungsten ores are known at present, the most important of which are situated in the departments of La Paz and Potosi. Exports were estimated at $89,932 in 1911 and $114,847 in 1912. The crushed ore is concentrated on tables. Wolfram concentrates containing tin are calcined and treated by magnetic separation. Sometimes silver occurs in the tungsten or tin ores.

Definition of Adulterated or Loaded Leather. UNION OF SOUTH AFRICA. (*Board of Trade J.,* July 2, 1914.)—The definition of "adulterated or loaded leather" has been revised and now reads as follows: "Adulterated or loaded leather" shall mean leather (other than chrome or other mineral and combination leathers) that contains more than 3 per cent. of mineral ash, or more than 2 per cent. of glucoses and dextrinoids, or any organic matters, other pure tannins, fats, oils, wax and stearine, that are essential to the manufacture of leather. Chrome and other mineral and combination leathers shall not, however, have added thereto, or be loaded with, barium, lead or tin compounds, or magnesium sulphate or sodium sulphate."

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